AEROSPACE ENGINEERING

Part 1 of 2 parts — Vol. 20, No. 9

Boeing Dyna-Soar Manned Space Glider

Garrett is now developing Dyna-Soar's thermal control system—again demonstrating its 20-year leadership in the pioneering of airborne cooling methods by its AiResearch Manufacturing Divisions.

An important contribution to the rapid over-all development of the Boeing Dyna-Soar manned space glider, the compact, lightweight system will cool the pilot and his equipment, economically utilizing the cryogenic hydrogen fuel of the accessory power system.

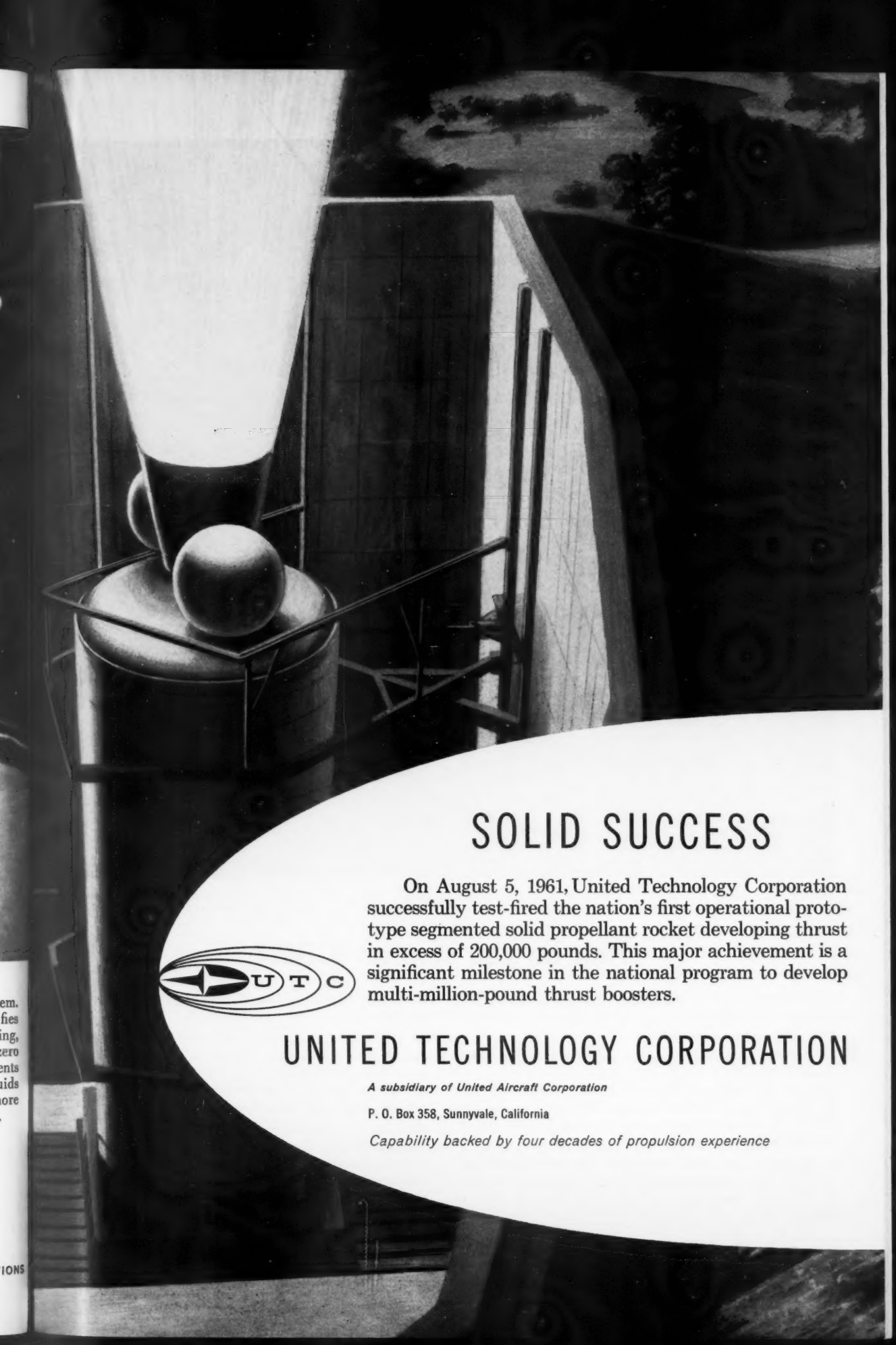
The development of this hydrogen system exemplifies Garrett's continuing advancements in airborne cooling, including air cycle and Freon refrigeration systems, zero gravity gas and liquid systems, and new developments in space radiators and other systems using exotic liquids and metals...all leading to the development of more advanced thermal control techniques for spacecraft.

THE GARRETT CORPORATION

AiResearch Manufacturing Divisions

Los Angeles 45, California • Phoenix, Arizona

Systems and Components for: AIRCRAFT, MISSILE, SPACECRAFT, ELECTRONIC, NUCLEAR AND INDUSTRIAL APPLICATIONS



SOLID SUCCESS

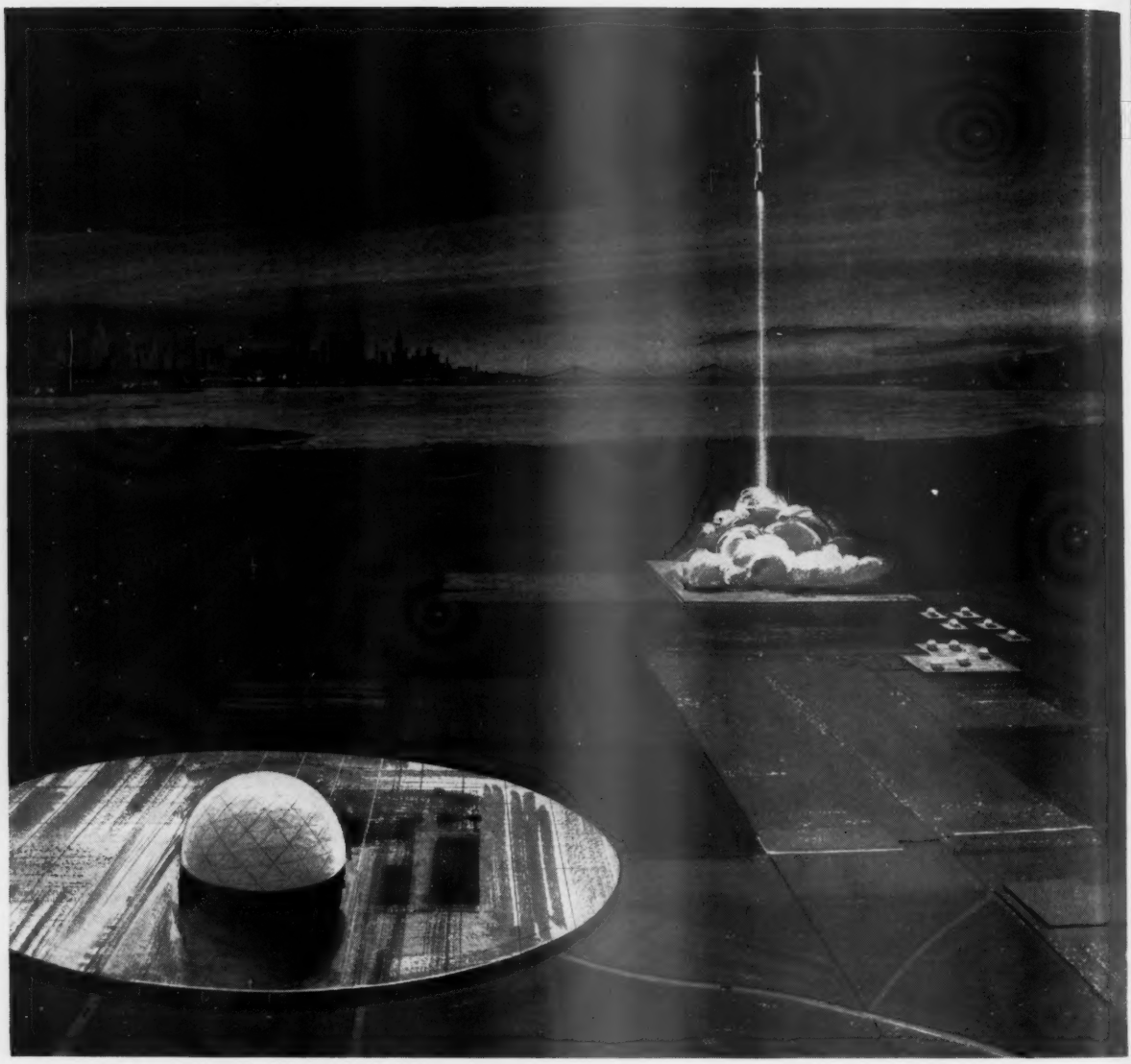
On August 5, 1961, United Technology Corporation successfully test-fired the nation's first operational prototype segmented solid propellant rocket developing thrust in excess of 200,000 pounds. This major achievement is a significant milestone in the national program to develop multi-million-pound thrust boosters.

UNITED TECHNOLOGY CORPORATION

A subsidiary of United Aircraft Corporation

P. O. Box 358, Sunnyvale, California

Capability backed by four decades of propulsion experience



More than 450,000 pounds of thrust lifts the U. S. Army's Nike Zeus missile skyward in a cloud of vapor. The Nike Zeus missile being developed for the project by the Douglas Aircraft Company will be designed to intercept ballistic missiles traveling over 15,000 miles per hour, and destroy them at a safe distance from the defended area.

How do you stop an ICBM?

How do you detect, track, intercept—and destroy within minutes—an ICBM that is moving through outer space ten times faster than a bullet?

Bell Telephone Laboratories may have designed the answer: Nike Zeus, a fully automated system designed to intercept and destroy all types of ballistic missiles—not only ICBM's but also IRBM's launched from land, sea or air. The system is now under development for the Army Ordnance Missile Command.

Radically new radar techniques are being developed for Nike Zeus. There will be an acquisition radar designed to detect the invading missile at great distances. And a discrimination radar designed to distinguish actual warheads from harmless decoys that may be included to confuse our defenses.

The system tracks the ICBM or IRBM, then launches and tracks the Nike Zeus missile and automatically steers it all the way to intercept the target. The entire engagement, from detection to destruction, would take place within minutes and would span hundreds of miles.

Under a prime Army Ordnance contract with the Western Electric Company, Bell Laboratories is charged with the development of the entire Nike Zeus system, with assistance from many subcontractors. It is another example of the cooperation between Bell Laboratories and Western Electric for the defense of America.

BELL TELEPHONE LABORATORIES

World center of communications research and development

"Written Exclusively
By Engineers—For Engineers

AEROSPACE ENGINEERING

– Established 1934 –

VOLUME 20 / NUMBER 9, Part 1 **SEPTEMBER 1961**

Featured in this Issue

Editorial 7 In Memoriam—Edward Raymond Sharp, 1894–1961

Edward R. Manring 8 Optical Tracers for Atmosphere Soundings

William H. Stuart 10 Satellite Attitude Stabilization by Means of Flywheels

Mark R. Nichols 12 Supersonic Transport Propulsion Requirements

Jerome E. Fischler 14 Modes of Failure of a Hypersonic Re-Entry Glide Vehicle

W. M. Aubin 16 Some Considerations of the Effects of Mission on Roll Requirements

Paul T. Cooper 18 The Role of the National Missile Ranges in Support of Space Operations

Philip A. Henning 20 Directional Stability and Control With a Single Gyro

William S. Johnson, Jr. and George W. Martin 22 An Aerodynamic-Influence-Coefficient Procedure

Luis de Florez 24 Weather—Take It or Make It

John V. Breakwell 26 Approximations in Flight Optimization Problems

Departments 28 Aerospace Technology as Seen by the Panels— *A New Feature*
Aeroelasticity—It Still Poses Important Problems, R. L. Bisplinghoff; Communication—Will the U.S. Be First in Space?, Peter C. Sandretto; Operations—V/STOL Worries Lie Ahead, Benjamin S. Kelsey

31 Adventures in Engineering— *A New Feature*
History's Most Elusive Paper Cup, George Blackburne

57 IAS Papers

63 IAS Special Publications

83 Personnel Opportunities

84 Index to Advertisers

On our cover

Development and expansion of a sodium cloud in the upper atmosphere (see E. R. Manring article on page 8) is depicted in an illustration based on a photo which also was a pattern for the accompanying drawing. The cloud is viewed as though on a celestial dome, with the center section (E) at a high point of 140 km. Initial vapor released at 70 km. (A) is $2\frac{1}{2}$ minutes old with small diameter due to low rate of expansion at this altitude. Marked wind shears are noted at 95 km. (B) and at 125 km. (D), while turbulence onset occurs at 105 km. (C). Rapid expansion is pictured at the high point (E), where vapor is one minute old. Rocket position at the time of the photo (F) is on its back-to-earth leg at about 120 km.—*Illustration by Joanna Larsen, Geophysics Corporation of America*

AEROSPACE ENGINEERING EDITORIAL STAFF

ESTABLISHED 1934

Publisher: **Welman A. Shrader**

Editor: **Allan Bernhardt, AIAS**

Associate Editor: **Paul J. Burr, AFIAS**

Technical Consultant: **R. L. Bisplinghoff, FIAS**

Editorial Production Manager: **Vehig S. Tavitian**

Editorial Assistant: **Helen S. Goldman**

AEROSPACE TECHNOLOGY PANELS

* Indicates Chairman

Paul J. Burr, IAS Technical Services Director, Coordinator

Aerodynamics and Fluid Mechanics

Lester Lees*
Seymour M. Bogdonoff
Dean R. Chapman
Antonio Ferri
Paul Germain
Wayland C. Griffith
Hans W. Liepmann
C. C. Lin
Henry T. Nagamatsu
W. R. Sears
John R. Sellars
R. T. Whitcomb
Hideo Yoshihara

Aeroelasticity

R. L. Bisplinghoff*
Y. C. Fung
I. E. Garrick
Martin Goland
Kurt H. Hohenemser
J. C. Houbolt
W. P. Jones
W. J. Mykytow
Robert F. Speaker

Biomedical Sciences

Brig.Gen. Don Flickinger, USAF*
W. Ross Adey
Capt. William Augerson, USA
Stuart Bondurant
A. Scott Crossfield
Cdr. J. H. Ebersole, USN
W. R Lovelace, II
Capt. Bruce Pinc, USAF
Stanley C. Roscoe
Foreign Correspondent,
Hilding Bjurstedt

Communication

P C. Sandretto*
K. C. Black
James M. Bridges
Harvard L. Hull
Leonard Jaffe
David S. Little
Lt. Cdr. M. M. Macomber
Cdr. D. O. Mann, USN
Paul Rosenberg
William Sen
Arnold Shostack
Teck A. Wilson

Control & Guidance

Robert N. Brown*
B. Paul Blasingame
S. F. Eyestone
C. E. Gallagher
Percy Halpert
B. J. O'Connor
Robert L. Roderick
S. F Schmidt
O. Hugo Schuck
H. Philip Whitaker

Energy Conversion

David Altman*
Robert Bromberg
M. U. Clauser
J. Preston Layton
Frank Marble
G. H. Markstein
A. M. Rothrock
Milton M. Slawsky
Martin Summerfield
T. Y. Toong

Flight Mechanics

H. J. Kelley*
Malcolm J. Abzug
H. Julian Allen
A. E. Bryson, Jr.
T. N. Edelbaum
William C. House
George Leitmann
Bernard Maggin
Angelo Miele
John D. Nicolaides
Charles B. Westbrook

Instrumentation

Paul F. Bechberger*
J. M. Hungerford
Mac Lowy
Walter McKay
M. David Prince
Charles P. Sonett
George I. Toumanoff
William A. Wildhack

Management

Edward A. Ledeen*
Garrett C. Covington, Jr.
Maj. Gen. Marvin C. Demler, USAF
Richard G. Folsom
Joel M. Jacobson
Boyd C. Myers
Sidney M. Robbins
Lewis A. Rodert
John H. Sidebottom
R. C. Siebold
Paul Torda

Meteorology

Thomas F. Malone*
Robert D. Fletcher
Henry T. Harrison
Joseph Kaplan
Donald T. Perkins
Herbert Riehl
Morris Tepper
Clayton Van Thullenar
Harry Wexler

Nuclear Applications

J. Donald Rauth*
Jack L. Armstrong
Robert W. Bussard
H. M. Dieckamp
Capt. R. L. Duncan, USN
Harold B. Finger
Donald J. Keirn
Frank E. Rom
Raymer E. Schreiber
D. Roy Shoults
T. B. Taylor

Operations

Richard V. Rhode*
Maj. Gen. Otis Benson, USAF (MC)
Ernest A. Cutrell
Capt. E. E. Fawkes, USN
Melvin N. Gough
Franklin W. Kolk
Col. J. L. Marinelli, USA
W. E. Rhodes
M. B. Spaulding, Jr.
Maj. Gen. D. N. Yates, USAF

Propulsion Systems

Bruce T. Lundin*
Robert H. Boden
George W. Brady
David Cochran
Elliot Mitchell
Perry W. Pratt
C. C. Ross
John G. Wilder, Jr.
Maurice J. Zucrow

Space Physics

John C. Evvard*
Herbert Friedmann
Leo Goldberg
C. F. Hansen
Arthur Kantrowitz
Bruno Rossi
S. F. Singer
Leo Steg
Fred L. Whipple

Structures and Materials

Nicholas J. Hoff*
Samuel B. Batdorf
Bruno A. Boley
Pol Duwez
R. R. Heldenfels
Samuel Levy
George N. Mangurian
S. S. Manson
Nathan E. Promisel
Ernest E. Sechler

Support

Ernest G. Stout*
Albert D. Brown
Edward I. Brown
Col.Paul T. Cooper, USAF
P. J. Daniel
Paul Hartline
Donald R. Hill
Capt. N. D. Hodson, USN
Lt. Col. George L. Lovett
R. R. Malik
John McKenna
Gilbert Rolan
Richard A. Schmidt
William R. Owens

Vehicle Design

C. E. Pappas*
Ralph Alex
Adolph Burstein
C. H. Christenson
A. J. Eggers, Jr.
Robert Lichten
E. V. Marshall
Rene H. Miller
John R. Ragazzini
George S. Schairer
George S. Trimble, Jr.

Aerospace Engineering (established 1934) is published monthly by the Institute of the Aerospace Sciences, Inc., at 20th and Northampton Streets, Easton, Pa. Headquarters and Editorial Offices: 2 East 64th Street, New York 21, N.Y. (TEmpleton 8-3800). Western Office: 7660 Beverly Blvd., Los Angeles 36, Calif. Subscription rates: United States and possessions, 1 year, $5.00; single copies, $0.50. Foreign countries including Canada (American currency rates), 1 year, $6.00; single copies, $0.50. Second-class mail privileges authorized at Easton, Pa. This publication is authorized to be mailed at the special rates of postage prescribed by Section 132.122. Notices of change of address should be sent to the Circulation Department, Institute of the Aerospace Sciences, Inc., 2 East 64th Street, New York 21, N.Y., at least 30 days prior to actual change of address.

© Copyright, 1961, by the Institute of the Aerospace Sciences, Inc.

Statements and opinions expressed in *Aerospace Engineering* are to be understood as individual expressions and not those of the Institute.

BUSINESS STAFF

Business Manager and Advertising Production

John Phillips

Advertising Director

John R. Cockerell
116 So. Michigan Ave.
Chicago 3, Ill.
ANdover 3-6929

National Advertising Regional Offices

John Cockerell, Inc.

(Headquarters)
116 So. Michigan Ave.
Chicago 3, Ill.
ANdover 3-6929

3757 Wilshire Blvd.
Los Angeles 5, Calif.
DUnkirk 3-1135

380 Lexington Ave.
New York 17, N.Y.
OXford 7-9048

1501 Euclid Ave.
Cleveland 15, Ohio
TOwer 1-8338

915 Olive Street
St. Louis 1, Mo.
GArfield 1-0907

141 N.E. Third
Miami 32, Fla.
FRanklin 1-9941

Contributors Please Note

AEROSPACE ENGINEERING welcomes contributions of full-length technical articles, including manuscripts classified as technical notes, pertaining to all fields of interest in the Aerospace Sciences. (See headings of IAS Aerospace Technology Panels on opposite page.) Manuscripts in either category, which should be addressed to The Editor, *Aerospace Engineering*, 2 East 64th Street, New York 21, N.Y., are acknowledged on receipt. Editorial review—requiring from two to six weeks—is initiated with a promptness dependent upon conformance to standards discussed below. Authors are notified as soon as possible as to acceptance or rejection. To avoid delays and minimize correspondence, contributors are urged to supply the Editor with the original manuscript plus one or two legible (carbon or process) copies complete with clear copies of illustrations. Manuscripts should not exceed 17–20 pages (maximum of 5,000 words). Each should be typed (double-spaced) and every page must be typed with two-inch margins. For each illustration, deduct 350 words; for any tabular matter, deduct an equivalent number of words from text. Detailed instructions for preparation of manuscripts are published monthly on the inside back cover of the *Journal of the Aerospace Sciences*. *Aerospace Engineering* does not pay for contributions.

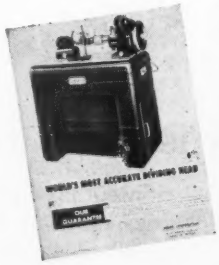
WORLD'S MOST ACCURATE OPTICAL DIVIDING HEAD

VINCO GUARANTEES the Optical Master Inspection Dividing Head to be accurate within ± 1 second of arc; the ball bearing spindle runout to be 25 MILLIONTHS of an inch, total indicator reading; the master disc graduations to be spaced to an accuracy within ± ½ second of arc.

Shown above is a heavy duty dividing head and a dual recorder console with a ball slide electronic indicator stand. This ultra precision equipment will check and record tooth to tooth errors and accumulated errors to within 50 millionths of an inch on a 15" D.P. gear. Single recorder consoles are available.

DIVIDING HEAD APPLICATIONS

- Inspection of missile guidance system components.
- Measurement of gear and spline spacing and bore relationships.
- Calibration of index plates, involute and master involute profiles.
- Calibration of lead bars or helical precision components.
- Inspection of two and three dimensional cams as well as ellipses, cycloids, etc.
- Measurement of angular transmission of motion by gears and gear trains.
- Measurement of angular displacement of turntables.



SEND FOR THIS FREE EIGHT PAGE BROCHURE. THE DIVIDING HEAD IS FULLY ILLUSTRATED AND EXPLAINED.

A 720 TOOTH, 32 D.P. 14½° P.A. PRECISION GEAR

Tolerances on this 22.500" P.D. gear are .0002" involute profile; .0003" T.T.E.; .0006" T.C.E. The same craftsmen who build the world's most accurate dividing head produce gears of even closer tolerances daily for use in missile guidance systems, jet aircraft, instrumentation or wherever needed. **Call Vinco on your sub-contract requirements.**

VINCO DIV., VINCO CORP.

9111 SCHAEFER HIGHWAY • DETROIT 28, MICHIGAN

Concrete loudspeaker horn is 47 feet x 30 feet—the largest in the world.

Mach 3 Technology

Torturing aircraft structures with the world's largest "gramaphone"

To predetermine in-flight stresses on an aircraft as advanced as the Air Force's Mach 3 B-70 Valkyrie, it was necessary to make sweeping advances in the state-of-the-art of testing procedures.

One way the Los Angeles Division of North American Aviation met this challenge was to build the largest, loudest acoustical test chamber in the world. Here, a mammoth 47 foot by 30 foot concrete loudspeaker horn can blast aircraft structural specimens with up to 170 decibels of noise. This is the equivalent of 54,000 five-tube radios going full blast, yet ingenious soundproofing keeps this noise to no more than a discreet whisper outside the lab. The noise inside the lab is so great that the heat generated could ignite fiber glass insulating material.

Specimens up to 6 feet by 25 feet can be tested in the acoustical lab. It has the capacity for: progressive wave as well as reverberant sound fields; grazing or normal incidence specimen orientation; discrete frequency or random noise at sound levels up to 170 dbs; thermal environment testing from $-100°F$ to $+1200°F$; frequencies of 50 to 10,000 cycles per second. This is indeed a remarkable facility for acoustical testing, fatigue testing, and vibration testing.

This giant acoustical laboratory can not only carry out testing on tomorrow's Mach 3 aircraft, but can perform tests on aerospace craft still ten years from reality. The lab is only one of the many that the Los Angeles Division has developed to conquer problems of space age flight.

Builders of the B-70 Valkyrie

THE LOS ANGELES DIVISION OF NORTH AMERICAN AVIATION

In Memoriam—

EDITORIAL

Edward Raymond Sharp 1894 - 1961

DR. EDWARD RAYMOND SHARP—"Ray" to most of us —IAS President in 1956, Director Emeritus of the NASA Lewis Research Center, died on July 24 at his Lakewood home after a long illness.

Funeral arrangements were private—restricted to family—but a Memorial Service was held at the Administration Building of the Center at 2:00 P.M., Sunday, July 30, attended by family and many friends and associates. E. J. Manganiello, FIAS, Acting Director of the Center, presided. Because his remarks so well rounded up Ray's character and accomplishments we reproduce them here, in part.

"We are gathered here today on these grounds he loved so much to pay tribute to our gifted leader and valued friend, 'Ray' Sharp.

"We all know well his record of achievement and well-deserved honors. We all have shared in the warmth of his friendship; and we all have profited from the wisdom of his counsel. It is most difficult to find adequate words to measure his character, his personality, and his impact on our professional and personal lives.

"Because this choice of words is so difficult, let me borrow a statement from Disraeli. He said, 'Life is too short to be little.' This expressed perfectly the person, the philosophy and the character of Ray Sharp. He was not little. He was big; big in everything—in person, in the enjoyment of life, in ideas and ideals, in humanitarianism, and in the conception and execution of all enterprises with which he was associated. This full measure of competence, hope, courage, and resourcefulness was infectious to those around him and provided the solid foundation upon which many a dream was shaped into reality.

"The Nation's overall aeronautical and aerospace technology owes much to Ray Sharp's vision and leadership during his more than 37 years of service to NACA–NASA. The expansion of the Langley Laboratory where he served for many years, the construction of the Ames Laboratory, the building and directing of this, the Lewis Center—these are the visible accomplishments of his efforts. These buildings, facilities and equipment collectively comprise the finest and most effective aerospace research tools that exist in the world. They deserve a large share of the credit for the impressive development of this country's outstanding aircraft.

"But of even greater importance is the caliber and competence of the personnel developed by Ray Sharp to operate and utilize these facilities to produce research results. The highly trained and highly motivated staff of the laboratories constitute the most significant contribution Ray has made to the business. They represent the most valuable legacy he leaves us.

"Ray was accorded many honors and distinctions throughout his career. He treasured most and held closest to his heart his recent award of the NASA Medal for Outstanding Leadership which was his organization's highest recognition for a distinguished career in its service. The Medal's accompanying citation summarizes concisely Ray's achievements. I quote: *'This signal honor has been made because you have demonstrated outstanding leadership throughout your career, in the maintenance and improvement of research operations during agency growth; in the training of men to meet the agency needs for critical skills, ranging from the apprentice crafts and trades to the major technical and executive levels; in the development and growth of aeronautical and space research facilities which enabled the Lewis Research Center to meet critical military objectives in World War II and in the administration of the propulsion research program at the Lewis Research Center.'*

"Ray equally treasured his election to the Presidency of the Institute of the Aerospace Sciences in 1956 which constituted recognition of, and respect for, his stature and accomplishments by the professional aeronautical community of the entire country. And, beyond this country's borders, we find many men who knew and respected Ray Sharp, scientists, engineers, educators, mechanics, and indeed anyone who works in the aeronautic and space business throughout the world. They knew him well, not only in Cleveland, Washington, Seattle, Los Angeles, but also in London, Paris, Geneva, Milan.

"To have known Ray, one came to know the tremendous vitality and dynamicism of the man, the wide ranging intellectual capacity, the amazing memory, the unswerving loyalty and dedication to duty, the eternal youth of spirit, ideas, and concepts. Lewis Laboratory, its staff and its many alumni who have transferred to other activities constitute Ray's living monument and embodiment. As long as the Lewis Laboratory exists and as long as we who learned from him exist, the things he stood for and worked for will be preserved in his spirit to the best of our abilities."

Optical Tracers for Atmosphere Soundings

Edward R. Manring

Geophysics Corporation of America

DURING EVENING TWILIGHT of October 12, 1955, sodium vapor was released into the upper atmosphere[1] from a sounding rocket to study the so-called "yellow flash," which is an apparent enhancement of the characteristic yellow light scattered by naturally occurring sodium atoms. In addition to the primary object of the experiment, important data were obtained by special photographic techniques which recorded an image of the cloud for further detailed study. The data on the cloud motions and expansion, as will be discussed in this paper, can be related to important characteristics involving atmospheric dynamics and chemistry.

Since all measurements of atmospheric properties have scientific value if they lead to new information, almost any well-planned contamination experiment can be expected to provide information of a scientific nature. In the past, almost all sounding rockets releasing contaminants have been flown for scientific purposes. Since 1955, about 80 rockets have been flown for experiments which release contaminants. Programs are being conducted in this country by the National Aeronautics and Space Administration and the Air Force. Similar programs are taking place in Britain, France, and Italy. The experiments, for the most part, have been concerned with studying winds and dynamics, the chemistry of the upper atmosphere, and the characteristics of electron production in the atmosphere. The region explored has extended from a height of approximately 70 km to approximately 700 km.

Dr. Manring joined GCA, Bedford, Mass., at the time the company was founded in 1958 and is now manager of the Observational Physics Department, where he has developed sensitive photometric and photographic methods for measurement of low light level luminescence. He served with the Air Force Geophysics Research Directorate from 1953 to 1958 and, as chief of the GRD Spectroscopic Studies Branch from 1956 to 1958, was responsible for upper atmosphere research in the fields of aurora, airglow, and meteor physics. While with the Air Force he also developed meteorite detection apparatus for both the Explorer I and III satellites. He received his B.S. degree in physics from Ohio State University in 1949 and served on the university staff as a research associate in physics until he obtained his Ph.D. there with honors in 1953

Regions of Application

Measurements attainable by studying the effects upon the atmosphere and upon the tracer used when a contaminant is released produce data of widespread importance. A few of the more salient applications for the data are listed here.

Spread of Debris or Contaminations

Experimental materials can be found which have very good optical properties and which are in no way harmful or dangerous. Small amounts of such material suffice to study empirically the rate at which materials released into the upper atmosphere (a) spread over the earth both by winds and by diffusive or turbulent expansion, (b) combine chemically, and (c) fall out of the atmosphere. Satellites and space vehicles re-entering the earth's

"Contamination experiments are easily performed from a rocket standpoint . . . The experiments are relatively cheap and obtain independent measurements which in many cases provide the only known means of measurement."

atmosphere[2] may, in the future, contain offensive or dangerous constituents. In particular, future missiles will probably carry radioactive and fissionable materials for primary and secondary power sources. It may be important to know the residence times of such materials in the atmosphere when the vehicle burns up during re-entry and, alternatively, to destroy the vehicle at a higher altitude where longer residence times are possible. In either instance, the data obtained on the observed motion and residence time of an inoffensive trace material may provide the needed answers.

Satellite Drag

The drag force on a satellite is a function of its cross-sectional area perpendicular to its velocity; it is a function of the medium density through which it travels and to the vehicle velocity squared. Other forces have been considered to be very small and are usually neglected. Since satellite cross sections are known and velocities and positions can be measured, the observed change in velocity has been used as a measure of ambient density. These measurements have been very useful, but contain some inconsistencies. It is possible, therefore, that drag forces other than the simple ones considered so far may be involved. Independent measurements of the ambient density are therefore desirable for their own value and to study further the dynamics of satellites moving through a medium. The only direct measure- (*Continued on page 34*)

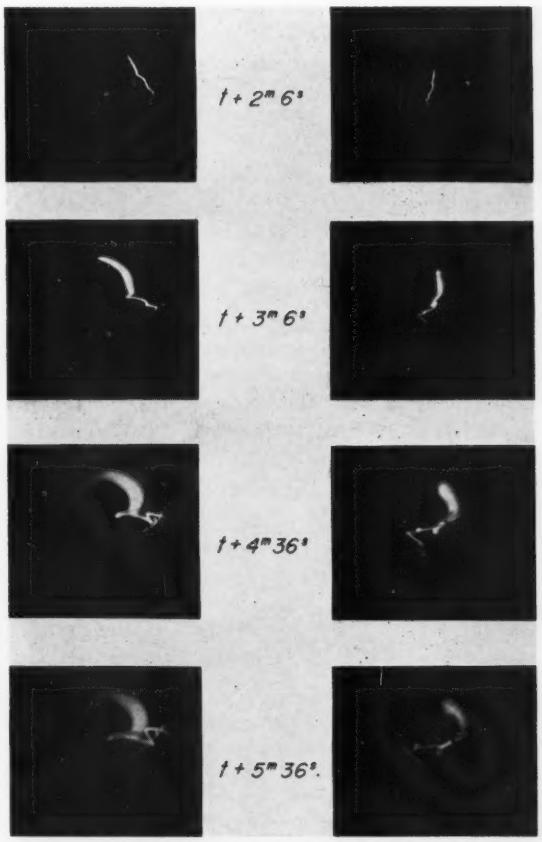


Fig. 1. Series of photographs taken April 21, 1961, at 0439 hours from Dover AFB, Del. (*left*), and from Camp A. P. Hill, Va. (*right*). Times after missile launch are recorded.

Satellite Attitude Stabilization

William H. Stuart, AIAS

Captain, United States Air Force

Captain Stuart is a graduate of the U.S. Military Academy, class of 1953. Upon graduation he joined the U.S. Air Force and was engaged in base civil engineering work for the next 5 years. Under sponsorship of the Air Force Institute of Technology, he then attended the University of Michigan where, in 1960, he received an M.S.E. (Instrumentation) and an Ae. & Astr. E. Captain Stuart is now assigned to the Weapon System Engineering Branch of the Site Activation Task Force, Dyess AFB, Texas, engaged in installation and checkout of Atlas ICBM's. He is a member of the University of Michigan chapters of Phi Kappa Phi and Sigma Xi.

BEFORE IT IS possible to set about developing the equations describing a satellite's attitude deviation, one must first define a reference axis system with respect to which the attitude deviations are to be sensed. Surprisingly, a great number of configurations are possible. For instance, one might wish the vertical axis to be directed always to the earth's center, or to be as determined by a horizon scanner, or colinear with the local gravitational vector. Each of these choices would be slightly different. We may require the forward reference to be normal to the selected vertical and in the instantaneous plane of the satellite's motion, or one might require this reference to be in the apparent plane of motion as seen by an observer on the earth. There are still other choices available, and the final choice will depend primarily upon the most practical means of sensing available.

For purposes of this investigation, the vertical axis is taken as the line connecting the earth's center and the center of mass of the satellite, pointed outward from the earth; the forward axis is in the instantaneous plane of motion; and the transverse axis is perpendicular to the plane determined by the vertical and forward axes, forming a right-hand set. The reference axis system is the primed system as shown in Fig. 1.

For a detailed discussion of the possible choices of reference axes, the reader may consult reference 1.

This research project was performed in partial fulfillment of the requirements for the Professional Degree, Aeronautical and Astronautical Engineer, at the University of Michigan, Ann Arbor, Mich., August 1960.

The author wishes to express his appreciation to Prof. F. E. Beutler of the University of Michigan for his counsel and assistance in the preparation and presentation of this research project.

Equations of Motion

Euler Body-Axis Equations

For ease in analysis, xyz body axes are imbedded in the satellite coincident with the satellite's principal axes of inertia. The control system then shall be designed so as to attempt to keep the xyz set always aligned with the reference $x'y'z'$ axes. The Euler body-axis equations for principal axes are

$$I_x(d\bar{P}/dt) - (I_y - I_z)\overline{QR} = T_{xr} + T_{xg} + T_{xf} \quad (1.1)$$

by Means of Flywheels

A relatively simple control scheme is evolved based upon the analog computer simulation of the linearized equations of motion. This control scheme is applied to the nonlinear equations of motion for small angular motion of the system, and response characteristics are obtained, again by means of analog computer simulation.

$$I_y(d\bar{Q}/dt) - (I_z - I_x)\overline{PR} = T_{yr} + T_{y\theta} + T_{yf} \quad (1.2)$$

$$I_z(d\bar{R}/dt) - (I_x - I_y)\overline{PQ} = T_{zr} + T_{z\theta} + T_{zf} \quad (1.3)$$

where

$I_{x,y,z}$ = satellite principal moments of inertia where flywheels contribute to these inertias (for instance, x-axis flywheel contributes to I_y and I_z but not to moment of inertia about its own axis, I_x)

$\bar{P},\bar{Q},\bar{R}$ = angular velocity components along x, y, z axes, respectively, with respect to a Newtonian frame

T_{ir} = reaction torque about i-axis due to rotors

$T_{i\theta}$ = gravity differential torque

T_{if} = all other unpredictable forcing torques

Attitude control is to be effected by properly controlling the rotational characteristics of the rotors located on the principal axes. The reaction torques due to these rotors are

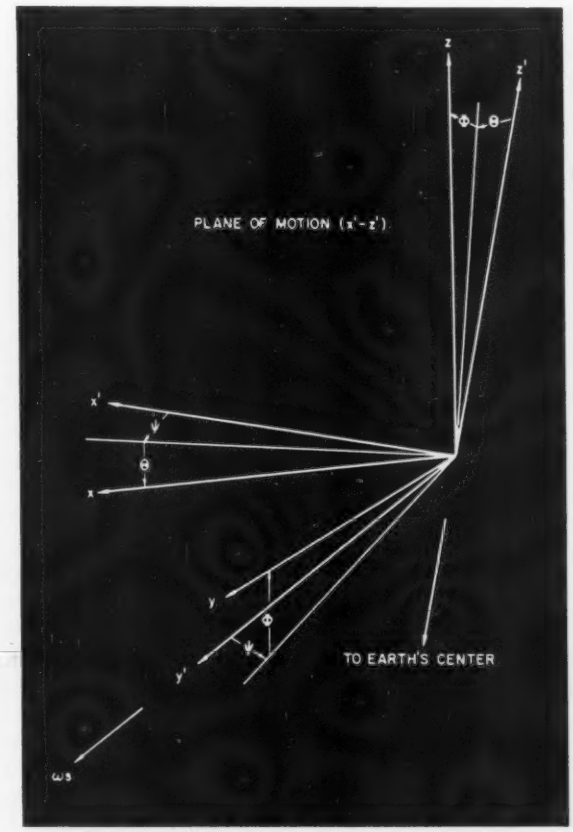
$$T_{xr} = -(dH_x/dt) + H_y\bar{R} - H_z\bar{Q} \quad (1.4)$$

$$T_{yr} = -(dH_y/dt) - H_x\bar{R} + H_z\bar{P} \quad (1.5)$$

$$T_{zr} = -(dH_z/dt) + H_x\bar{Q} - H_y\bar{P} \quad (1.6)$$

where H_i = instantaneous angular momentum of the rotor located on the i-axis. (*Continued on page 64*)

Fig. 1. Displacement of body axes from reference axes through Euler angles.



Supersonic Transport Propulsion Requirements

A realistic appraisal of propulsion requirements for a proposed supersonic commercial air transport.

Mark R. Nichols, AFIAS
Langley Research Center, NASA

NOW THAT A NATIONAL program for the development of a supersonic commercial air transport has been proposed,[1] it is time that a realistic reappraisal be made of the characteristics which the machine must have in order to ensure its success. The purpose of this paper is to review the propulsion part of the picture. In general, the material presented represents a composite view of the group conducting research in this area at the Langley Research Center of NASA.

In opening any such discussion, it is important to point out that detailed design objectives for the commercial supersonic air transport have not been defined. Some of the basic design unknowns which must be settled before a configuration can be established (Fig. 1) include: relative importance of commercial earning power, military usefulness, and national prestige; cruise Mach number as established by economic, technical, and prestige considerations; route structure required—that is, the question as to whether the machine is to be operated only on long international routes over oceans and uninhabited areas, or whether it will be required for economic and equipment interchange reasons to operate also on transcontinental and shorter routes over heavily populated regions; airport, noise, and traffic control limitations that will be in effect when the machine is introduced; new safety requirements such as fail-proof pressurization and air-conditioning systems; changes in passenger comfort requirements as affected by the reduction in trip time and changes in operating characteristics; required airframe life and engine overhaul times; and, finally, the nature of the anticipated new operating problems. This last unknown must be ranked on at least a par with the preceding items because of the very limited ex-

RELATIVE IMPORTANCE OF ;
- COMMERCIAL EARNING POWER
- MILITARY USEFULNESS
- NATIONAL PRESTIGE

CRUISE MACH NUMBER

ROUTE STRUCTURE

AIRPLANE SIZE AND PAYLOAD FLEXIBILITY

AIRPORT, NOISE, AND TRAFFIC CONTROL LIMITATIONS

NEW SAFETY REQUIREMENTS

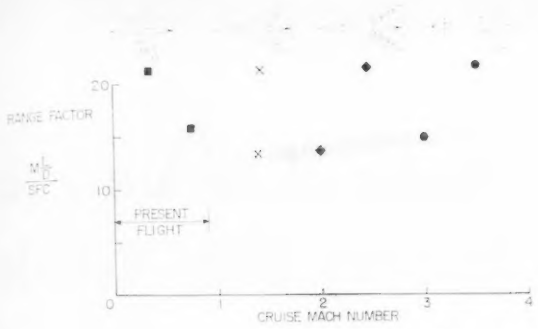
CHANGES IN PASSENGER COMFORT REQUIREMENTS

REQUIRED AIRFRAME LIFE AND ENGINE OVERHAUL TIMES

NATURE OF NEW OPERATING PROBLEMS

Fig. 1. Basic design unknowns.

Mr. Nichols graduated from Auburn University with B.S. degrees in aeronautical engineering (1937) and mechanical engineering (1938). He was employed from 1938 to 1940 as a mechanical engineer with Allis Chalmers Manufacturing Company, and from then to the present as an aeronautical engineer with the Langley Center of NACA (now NASA). He currently holds the position of Chief of the Full-Scale Research Division and is an Associate Fellow of the IAS.



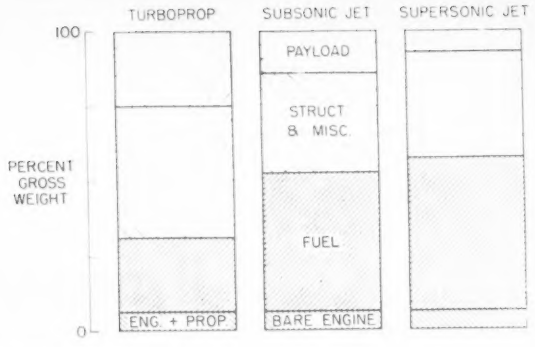


Fig. 2 (*left*). Jet transport cruise efficiency.
Fig. 3 (*right*). Typical transport weight breakdowns.

perience obtained to date with supersonic cruise aircraft in transport-type operations. For example, at Mach 3, a speed which is being considered extensively as the design cruise speed for the supersonic transport, the total manned flight time accumulated to date is but a few minutes.

On the basis of the Federal Aviation Agency proposal, it is apparent that the ability of the airplane to earn a profit for the commercial airlines outranks the considerations of military usefulness and national prestige. With regard to the other items listed, our studies have led to the belief that the machine must fly at a Mach number of at least 2, with growth potential to 3 or greater; compete economically over long-range domestic as well as overseas routes; be designed for payloads of approximately the same size as the present large jets; have acceptable levels of sonic boom over populated areas; be able to operate out of present international-type airports and in 1970-type traffic patterns with engine noise, safety, etc., comparable to or better than the present jets; have an airframe total life of 30,000 to 40,000 hours; and have engine time between overhauls of 1,000 to 2,000 hours. At the present time, no one has an airplane configuration—even a paper one—that is completely satisfactory with regard to all of these requirements. Nevertheless, the discussion presented will be centered about such an airplane on the assumption that it can be attained. The engine configuration that is optimum for the airplane will change somewhat, of course, if any of the assumed design objectives are changed or relaxed.

Discussion

Outline of Problem

The supersonic transport has become possible because of recent state-of-the-art advances in aerodynamics, structures, and engines that have produced major increases in cruise performance in the last few years. The present picture with regard to the attainable level of cruise efficiency is shown in Fig. 2 in terms of the range factor M $[(L/D)/\mathrm{SFC}]$ which is plotted as a function of cruise Mach number. The shaded band on the left was established from flight data from the present subsonic jet transports. The band on the right represents the results of calculations based on wind-tunnel test results for transport models, such as those illustrated, and averages of industry predictions of engine performance. Each of these configurations is optimized with regard to both aerodynamics and propulsion in the vicinity of its plotted cruise efficiency point and is significantly less efficient than the other configurations at their design points. It can be seen that predicted values of cruise efficiency for the supersonic machines are somewhat lower than those for the subsonic jets, but approach them closely enough to be considered competi- *(Continued on page 58)*

Modes of Failure of a Hypersonic Re-Entry Glide Vehicle

Jerome E. Fischler, MIAS, *Douglas Aircraft Company, Inc.*

SOME MODES of failure of a hypersonic re-entry glide vehicle that were found to be significant in the study of Refs. 1 and 2 are the object of the discussion of this paper.

A mode of failure can be either aerodynamic, dynamic, structural, or a combination of all three.

The structural engineer may visualize a mode of failure as a buckling failure, a fatigue failure, or exceeding a designated percent elongation limit. He is well aware that he must provide a flutter-free structure which also must be stiff enough to reduce the aero-thermal-elastic-plastic effects to a minimum. He must decide the mean stress values to use so that the fatigue and creep effects are small; he must evaluate the materials and type of construction which yield the minimum thermal stresses, have sufficient stiffness, are fail safe, and have a weight and cost that allow for the maximum payload.

The dynamics engineer may visualize a mode of failure as exceeding the dynamic stability limits, having poor handling characteristics, or having poor roll, yaw, or pitch effectiveness because of excessive aero-thermal-elastic losses. Also, severe buffeting, pitch-up, or inertia coupling at high angles of attack due to the nonlinearity of stability derivatives concerns the dynamics engineer. The nonlinearity of the stability derivatives is significantly increased as a result of the aero-thermal-elastic and plastic changes to the wing, fuselage, and control surfaces.

Therefore, the "melting pot" for the design is usually the compromises made between the dynamics engineer and the structural engineer on the "aero-thermal-elastic effects."

Before discussing other modes of failure, an example of what is meant by the "aero-thermal-elastic effects changing the stability derivatives" will be given. Figs. 1 and 2 taken from Ref. 1 show typical lateral stability boundaries. When the wing (Fig. 3) is exposed to the loads and temperatures of a selected flight profile (Figs. 4 through 7), the thermal deflections can be calculated using the temperatures of Fig. 8 and the chart of Fig. 9, or, if creep is significant, knowing the loading from Figs. 10 and 11, the total strain of the elements can be estimated from Fig. 12 for each mission.

Using the re-entry load spectrum of Fig. 13 and one g flight the rest of the time, the accumulated

Mr. Fischler has been a design specialist at Douglas since 1954. He has been head of the Advanced Vehicle Analysis Group, the Advanced Research Group, and the Loads and Criteria Group. He has a B.S. degree from M.I.T., and is enrolled in the graduate school at U.S.C. Mr. Fischler has assisted in developing advanced design on the Robo and Dyna-Soar proposals, has been Project Engineer on Air Force research contracts, and has helped in the loads and stress analysis of the C-133, RB-66, C-124 at Douglas, the Matador missile at Martin, and the XF-103 at Republic. At present, he is working on a supersonic transport.

Much of this work was performed in connection with Air Force Contract AF33 (616)–6680 under the auspices of the Materials Central, Directorate of Advanced Systems Technology, WADD, with R. F. Klinger acting as Project Engineer. The author wishes to acknowledge the help of those individuals noted in Ref. 1.

A mode of failure can be either aerodynamic, dynamic, structural, or a combination of all three.

strain can be estimated and converted into tip deflection. The accumulated strain assumes no recovery of the plastic strain (strain above yield stress from Fig. 14 plus creep strain). Note that the thermal stresses (Fig. 11) are added directly to the load stresses (Fig. 10) to obtain the plastic strain. Finally, a wing tip deflection after n flight missions is obtained. This deflection is called δ_n = tip deflection after n missions. Using this tip deflection, the change in the stability derivative $[\Delta Cl_\beta]_\Gamma$ can be calculated from the following equation in Ref. 3:

$$[\Delta Cl_\beta]_\Gamma = -2CL_{\alpha_{a\text{-}s}}\Gamma_{G_n}\eta_\Gamma \frac{\bar{y}}{b/2}$$

where

$[\Delta Cl_\beta]_\Gamma$ = change in rolling moment coefficient per degree sideslip per degree wing dihedral

$CL_{\alpha_{a\text{-}s}}$ = lift coefficient per degree angle of attack from an asymmetric wing loading (one side)

Γ_{G_n} = geometrical tip dihedral angle = $\tan^{-1}\delta_n/(b/2)$, $b/2$ = half span

η_Γ = wing dihedral effectiveness factor, a function of wing bending shape (Ref. 3)

$\frac{\bar{y}}{b/2}$ = percent of semi-span of lifting force for asymmetric loading

The change to the stability derivative Cl_β increases for each mission as the plastic strain accumulates.

Throughout the mission profile, the stability derivatives are changing (*Continued on page 36*)

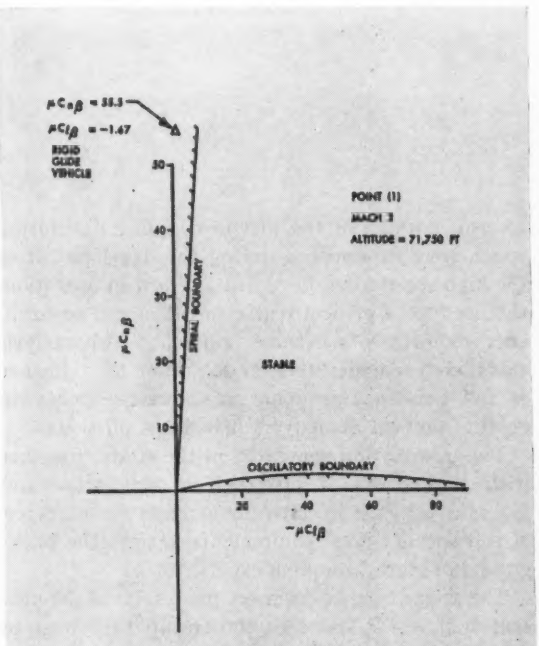


Fig. 1. Dynamic stability boundary for point (1).

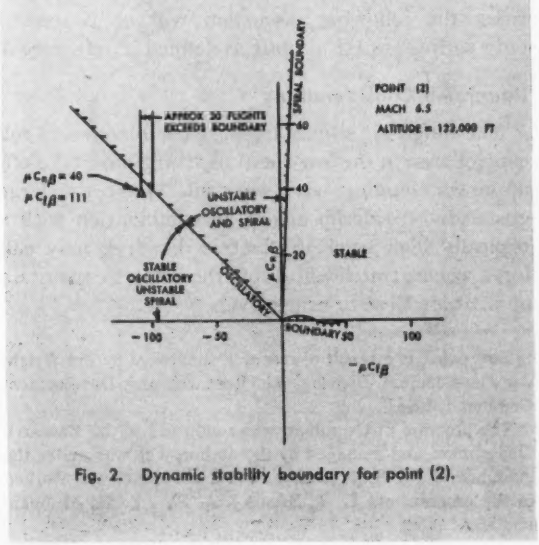


Fig. 2. Dynamic stability boundary for point (2).

Some Considerations of the Effects of Mission on Roll Requirements

W. M. Aubin, AIAS, *Grumman Aircraft Engineering Corporation*

IN THE COURSE of the inertia coupling difficulties, which were experienced during the development of the high-speed aircraft generation now in operation, the need for a critical reassessment of roll performance requirements became apparent. An analysis was therefore undertaken to determine the influence of roll performance upon an aircraft's ability to execute tactical maneuvers in various missions.

The information generated in the study, together with the results of pilot/vehicle simulation and flight investigations, provides a basis for a review of roll specification requirements against the background of inertia coupling experience.

The present paper discusses the results of the mission analyses[1, 2] and the relationship they bear to the present roll requirements.[3] Since the investigation was aimed almost exclusively at high-performance aircraft in the intercept and ground support roles, the following discussion will be concerned only with Class III aircraft as defined in reference 3.

Rough Air Considerations

The rough air situations most troublesome to roll control arise in the low-speed flight regime—take-off, approach, landing, and wave-off. Here the large gust-induced sideslip angles, in combination with a typically high level of effective dihedral, may call for a concentrated effort by the pilot to maintain an attitude close to wings-level.

This paper is a result of research sponsored by the Wright Air Development Division, Air Research and Development Command, USAF.

The program at Grumman was conducted in the Research Department and managed by the author, who was under the guidance of Dr. H. J. Kelley. Other personnel who worked in the program are H. T. Breul, J. A. Ebe, E. M. Millman, and P. A. Vitale.

Mr. Aubin has worked in the Research Department of Grumman snce 1953 when he obtained an undergraduate degree in aeronautical engineering from the University of Detroit. In 1957 he received a Master's degree in applied mathematics from Adelphi College. His interests at Grumman have covered subsonic aerodynamics and potential theory, dynamic stability, operations research, mission analysis, and feasibility and parameter studies. He is presently a Group Leader in the Special Projects Section of the Department.

An investigation of flight in rough air was performed in two phases. First, a linear analysis was conducted of a manually controlled aircraft flying in continuous random gusts. This work was correlated with a human pilot "flying" a simulator. The second phase of the study employed the human pilot "flying" a simulator to determine the effect of discrete gusts on the peak bank angle for a wide range of system parameters (control power and roll time constant). In both phases, the pilot, either mathematical or human, attempts to maintain a wings-level attitude while flying the aircraft.

The system analyzed in both cases was a one-degree-of-freedom approximation of the aircraft roll response to aileron input. The roll time constant T_R was varied by introducing a simple rate feedback term corresponding to idealized roll damping augmentation. The maximum control power was varied above that of the basic configuration by increasing control gain and varied below it by decreasing maximum aileron deflection.

Continuous Turbulence

Fig. 1 shows the system block diagram for the continuous random turbulence study. The linear

- *Roll performance required for any maneuver increased with the number of times the aircraft was required to bank-and-stabilize in the maneuver.*
- *Maximum useful roll performance for low-altitude maneuvers was at the same general level as the present flying qualities specification. High-altitude maneuvers studied showed, in general, a lower level of maximum useful roll performance.*
- *The fact that certain maneuvers are more dependent on roll damping than on roll control power became evident.*

pilot transfer function assumed consisted of a simple gain with a time delay. For comparison, a human pilot "flew" a stationary simulator with the horizon displayed on an oscilloscope.

Results of the analysis for a 10 ft/sec rms side gust are presented in Figs. 2 and 3 which show, respectively, the effect of roll time constant on twice rms bank angle and on twice rms aileron deflection. Fig. 2 shows the linear pilot performance for three pilot gains and two pilot reaction times. One human pilot curve is also presented. In spite of the relatively large side gust disturbance used, the bank angle never becomes excessive. Fig. 3 shows the linear pilot aileron motion for three pilot gains and one pilot reaction time. Results for the same human pilot are also shown. This latter curve vividly illustrates that neither the mathematical pilot nor the human pilot requires large amounts of roll control for the situation under study.

The mathematical and human pilot curves separate for high values of roll time constant because the human pilot at this point adapts to more complex behavior. He is undoubtedly employing some form of lead and/or lag[4, 5] to maintain control in the presence of low system damping compensation. Whenever he is forced into functioning in a more complex manner, his opinion begins to deteriorate. This is borne out by results[6] showing a deterioration of pilot opinion with increasing values of roll time constant.

Although results of this study do not indicate a need for roll control power, they do indicate a need for some minimum level of roll damping. The human pilot results show little or no increase in rms bank angle with roll time constant; however, as indicated in reference 6, the (*Continued on page 45*)

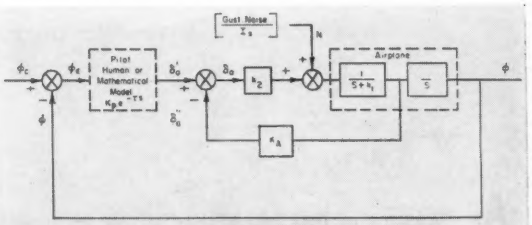


Fig. 1. Block diagram of linear system.

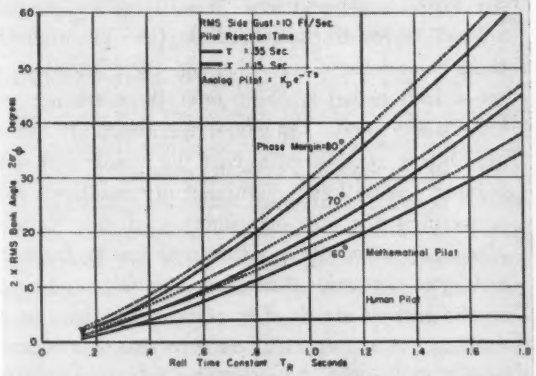


Fig. 2. Effect of roll time constant on rms bank angle for continuous random disturbance.

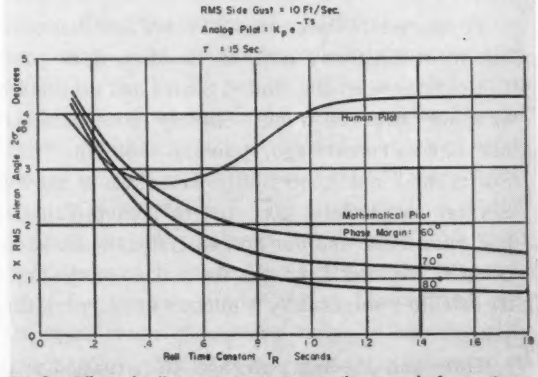


Fig. 3. Effect of roll time constant on rms aileron angle for continuous random disturbance.

The Role of the National Missile

Col. Paul T. Cooper, USAF
Office of the Secretary of Defense

Col. Cooper is Acting Assistant Director of Defense Research and Engineering (Ranges and Space Ground Support), responsible for coordinating the missile range and space ground support activities of the Department of Defense. He spent five years at Cape Canaveral in charge of range development and range operations as Deputy Commander, Air Force Missile Test Center. He has been in USAF research and development work since 1947. As a World War II lieutenant colonel, he commanded a medium bombardment squadron in the Mediterranean and flew 74 combat missions. He graduated from Purdue University in 1940 with a B.S.M.E. degree and has done graduate work at Stanford University and George Washington University. He is a graduate of the Naval War College and the Industrial College of the Armed Forces.

As a result of being headlined in the newspapers almost daily for the past several years, the launch support activities at Cape Canaveral, Vandenberg Air Force Base, and more recently at Pt. Arguello are well known to the general public. The organizations behind these activities and their recent emergence into global tracking operations are not well understood today. As global operations are becoming routine, it is essential that the missile and space industry, as well as government organizations, fully understand the support function of the National Missile Ranges. This article will briefly trace the history of our national tracking capability and report on the current status of tracking networks. In describing the management concept that has evolved, it will distinguish between the role of the range operator and the range user.

The Pre-Sputnik Picture

To appreciate the current status of facilities today, one must flash way back to the dim, dark past—to the time when the United States had no satellites or space probes to track. Slightly more than three and one-half years ago, January 1958, the United States had not successfully launched a satellite. Several unsuccessful attempts to launch Vanguard had been made and our first satellite, the Redstone-boosted Explorer I, was on the pad, to be the first of 31 satellites successfully launched in the next three years.

Three and one-half years ago, the situation at the two coastal National Missile Ranges, Atlantic Missile Range and Pacific Missile Range, was as follows.

Atlantic Missile Range—1958

Cape Canaveral was feverishly launching aerodynamic and ballistic missiles such as Matador, Bomarc, Snark, Navaho, Redstone, Thor, Jupiter, and an occasional Atlas amid a continuous cloud of dust caused by construction of new pads for Atlas, Titan, and Polaris. The range tracking stations were essentially complete to Ascension Island, although lacking much of the instrumentation and communications they now have. They were originally created for tracking aerodynamic missiles such as Snark and Navaho in the early 1950's. With some major changes in instrumentation, they were adapted to IRBM and ICBM support in 1955–6. They then

Ranges in Support of Space Operations

A brief history of national tracking capability and report of current status of tracking networks.

became ready-made facilities for our missile boosted space programs after Sputnik I.

On the West Coast, three and one-half years ago, the Navy was operating a range at Pt. Mugu, Calif., for aerodynamic missiles such as Sidewinder and Regulus. The USN had just received a directive from the Secretary of Defense officially designating them as the Pacific Missile Range, transferring Pt. Arguello real estate to the Navy as a launch facility well-oriented for polar orbits and directing that PMR support the forthcoming IRBM and ICBM training flights from the adjacent Vandenberg Air Force Base. At that time, the Pacific Missile Range had no requirements for supporting satellite launches, although such a launch was to occur 13 months later. In short, PMR had no off-shore tracking capability except for a single ship and they knew of no firm requirements for the future.

IGY Instrumentation

The only United States space vehicle tracking capability, in addition to the Atlantic Missile Range stations for tracking boosters during powered flight, consisted of facilities created in support of the IGY. The JPL-operated Microlock for Explorer and Naval Research Lab's Minitrack for Project Vanguard provided doppler and interferometer type station passage data respectively plus telemetry and timing. Minitrack is now functioning under National Aeronautics and Space Administration (NASA) control, with some additional sites, as a general purpose network for obtaining ephemeris information on all satellites. Also in furtherance of the IGY was the network of Baker-Nunn cameras installed throughout the world in 12 locations. These cameras are still in operation by the Smithsonian Astrophysical Observatory for-and-in-behalf-of NASA (Fig. 1).

Juno and Pioneer Tracking

So much for the picture of the situation three years ago. It would be very interesting to trace in some detail the chronology of events of the last three and one-half years and show the evolution which led to the current status of tracking networks throughout the world today. However, the following summary statements will suffice. When the Juno and Pioneer series of probes came into the picture, the Army developed the Trace network (Goldstone; Mayaguez, Puerto Rico; and Cape Canaveral) as an outgrowth of their Microlock techniques. The USAF developed the so-called Able net for doppler tracking and telemetry. The Atlantic Missile Range supported the launches in much the same manner as a ballistic missile would be supported in the launch phase. As an organization, AMR did not become involved in tracking beyond the point of insertion into orbit in the case of satellites or much beyond the point of first stage burnout in the case of deep space probes. As a matter of fact, project personnel, as distinguished from range personnel, frequently assumed the responsibility for tracking upper stages beyond the geographical reach of existing range instrumentation rather than placing their data requirements on the range since normally, (*Continued on page 51*)

Directional Stability and Control With a

Unique gyro provides both attitude and rate information for the stability and control of yaw and roll with outstanding simplicity. Best application for the device is in low-cost control systems where heading-hold performance is desired.

Philip A. Henning, *Guidance Technology, Inc.*

NUMEROUS MISSILE and man-carrying aircraft missions and essentially all target and drone applications require the performance of straight down-course runs as the basic azimuth pattern. However, there has been widespread aversion to the use of heading sensing elements due to the problems of complexity and/or high cost. To overcome these objections, the PAR (Position and Rate) Gyro has been developed and is being used as the single sensor for heading-hold performance and lateral mode stability in the Beech KDB-1 target and the Douglas A4D-1 aircraft. This single-degree-of-freedom gyro with an internal electromechanical integrator provides the desired yaw attitude signal for performing straight azimuth courses and senses the aircraft lateral rates for Dutch-roll stability augmentation, hence may replace both a directional gyro and a rate gyro in some applications or may be added to those systems wherein directional performance is desired but not at the price of a directional gyro and its associated complexities. Other advantages of the PAR Gyro design include a low-power proportional turn-rate command capability and simple mechanical caging. Productionized, qualified designs exist for both direct and alternating currents for low-cost target and long-life, high-reliability applications.

Mr. Henning is Director of Engineering of Guidance Technology, Inc. (formerly Summers Gyroscope Co.), Santa Monica, since 1953. He was in responsible charge of development of numerous guidance components and flight control systems as Project Engineer, Chief of Guidance and Control, and Chief Engineer. He received his B.S. in electrical engineering from Worcester Polytechnic Institute in 1944 and was elected to Sigma Xi and Tau Beta Pi honorary societies. He received his M.B.A. from the University of Southern California in 1953. He was associated with Sylvania Electric Products (Electronics Division) from 1946 to 1949, where he worked on radar systems design. From 1949 to 1953, he was with Gilfillan Bros., Inc., engaged in development of electronic countermeasure equipment.

PAR Gyro Principle

The PAR Gyro is a single-degree-of-freedom gyroscope, hence the gimbal output is a torque proportional to angular velocity about the gyro sensing axis. A conventional rate gyro has spring restraint of the gimbal to case and the gimbal displacement against the spring force is a direct measurement of angular velocity. The PAR Gyro has restraint to case by the combination of a spring and a geared eddy-current damper motor as shown in Fig. 1. The damper motor develops a restraining torque that is proportional to its shaft rotational velocity. This torque is amplified by gearing to apply a gimbal restraining force of the proper range for each PAR Gyro design. Thus, the restraining torque is proportional to gimbal velocity and the gimbal torque is proportional to gyro input angular velocity. The total angular displacement of the gimbal is proportional to the total angular movement of the aircraft about the gyro sensing axis. The

Single Gyro

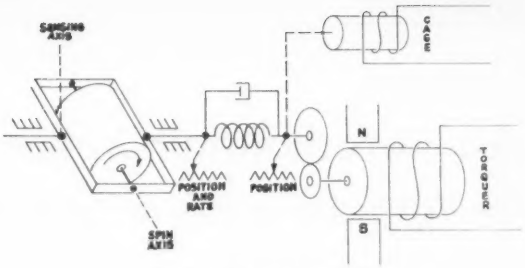


Fig. 1. Mechanical schematic.

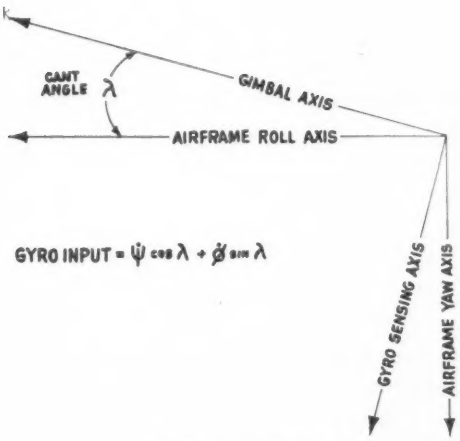


Fig. 2. Canted PAR Gyro.

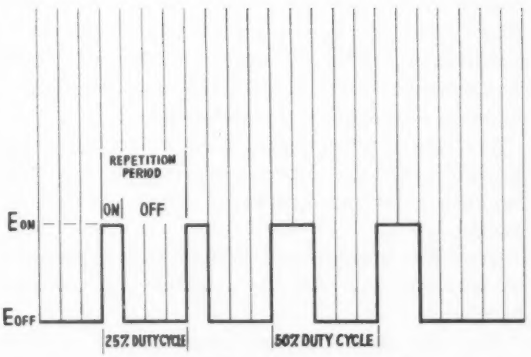


Fig. 3. Proportional turn-rate commands.

Symbols

A_t = inner gimbal tilt angle, deg
A_z = true azimuth angle, deg
E_p = PAR Gyro signal output at position pickoff, volts
E_{par} = PAR Gyro signal output at position and rate pickoff, volts
K_1 = PAR Gyro position sensitivity constant, volts/deg
K_2 = PAR Gyro rate sensitivity constant, volts/deg/sec
K_3 = aileron control gain factor, deg/volts
K_4 = rudder control gain factor, deg/volts
α = aircraft angle of attack, deg
δ_A = total aileron control surface angle, deg
δ_R = rudder control surface angle, deg
ϵ_ψ = error in true heading, deg
ϵ_{ψ_m} = error in magnetic heading, deg
λ = PAR Gyro cant angle, deg
$\dot{\phi}$ = aircraft roll rate, deg/sec
ω_t = angular velocity about PAR sensing axis, deg/sec
ψ_m = magnetic heading, deg
$\dot{\psi}_c$ = commanded aircraft yaw/rate, deg/sec
$\dot{\psi}$ = aircraft yaw rate, deg/sec

function of the spring between the gimbal and geared damper motor is to restore a fraction of the aircraft rate signal in the usual rate gyro fashion.

The PAR Gyro is similar to the well-known viscous restrained gyro in that both types are single-degree-of-freedom, rate-integrating sensors. However, the viscous restraint technique prevents the separation of rate sensing from integration, whereas the PAR has two distinct mechanical functions. This latter feature allows the inclusion of the spring between the gimbal and the integrator, hence the gyro is effectively a rate gyro plus an electromechanical integrator in a single package.

The PAR Gyro has two pickoff positions, as shown in Fig. 1. These pickoffs are at each end of the rate spring and (*Continued on page 73*)

An Aerodynamic-Influence-Coefficient Procedure

for Wings Having Supersonic Trailing Edges and Streamwise Tips

William S. Johnson, Jr., MIAS • George W. Martin

Convair, A Division of General Dynamics Corporation

A LARGE NUMBER of loading equations for specific wing modes are available in the literature; Kainer[3, 4] and Zienkiewicz[6, 7] may be mentioned in particular. Coding these equations for the computer and utilizing the solutions in a steady-state aeroelastic analysis can be long and tedious. An alternate approach is available in the aerodynamic influence coefficient matrix. An aerodynamic influence coefficient matrix $[A_{PJ}]$, may be defined as the pressure induced at a point P by placing a unit incidence on a subdivision J of the planform. An influence matrix has several advantages over the mode solutions in addition to simplicity of calculation:

(1) For a given Mach number one matrix can provide all the aerodynamic information of interest, symmetric and antisymmetric, rigid and induced loads.

(2) The matrix may be "empirically correlated" to whatever test data is available for the rigid planform.

(3) The slope influence block pattern may be constructed with apt consideration of the structural arrangement and deformation characteristics of the planform.

(4) The matrix may be inverted and utilized to solve for the chamber distribution required in a rigid wing to obtain a specific pressure distribution.

The authors gratefully acknowledge the assistance of Mr. Joy C. Green of Convair-Fort Worth in preparing the sample problems and Mr. Julian H. Kainer of Convair-Astronautics in reviewing the manuscript.

Mr. Johnson is a Project Structures Engineer in the Loads Group at Convair. He has responsibility for the steady-state aeroelastic analysis work on the B-58. Mr. Johnson joined Convair in 1948 and worked previously at Vought-Sikorsky and Martin (Baltimore) as a designer. He received the B.S. in aeronautical engineering from North Carolina State College in 1942, M.S. in aeronautical engineering from the California Institute of Technology in 1948, and M.S. in mechanical engineering (structures option) from Southern Methodist University in 1959. He was an aircraft maintenance officer for the Air Transport Command in the India-Burma Theater during World War II. Mr. Johnson is a member of the IAS.

Mr. Martin is a Senior Aerodynamics Engineer in The Martin Company Advanced Systems Group in Orlando, Fla. Prior to joining Martin to set up a static aeroelasticity program for supersonic missiles with low aspect ratio fins, he was a member of the Aeroelasticity Group at Convair-Fort Worth for two years. His current duties are with the Ground Effect Machine team specializing in stability and control studies. An honor graduate of Georgia Institute of Technology, he received a B.S. in aeronautical engineering in 1957 and, as the recipient of the Southern Airways Fellowship for Graduate Study, an M.S. in aeronautical engineering from the same school in 1959. He is a member of Tau Beta Pi, Phi Kappa Phi, and Sigma Gamma Tau.

The proposed solution is similar to the superposition concept of Woodward.[5] It differs from the Woodward method in that it is designed to be programed completely within a digital computer pro-

The method of calculation presented in this article is designed primarily for the aeroelastician who is interested in an easily programed steady-state aerodynamic solution that will give acceptable accuracy over a useful range of parameters. The aerodynamic matrix may be calculated for an arbitrary planform block-division and pressure pattern

Symbols

c_i = interim solution constants, Eqs. (C-1) and (C-2)
C_p = lifting pressure coefficient
m = $\beta \tan \epsilon$
M = Mach number
R = $1/\sqrt{(x-\xi)^2 - \beta^2(y-\eta)^2}$
S_w = region of integration for the velocity potential
V = velocity
x, y, z = Cartesian coordinates with origin at wing apex
x_w = distance apex axis basic planform to apex axis of working wing
α = angle of attack with respect to the free stream, radians
β = $\sqrt{M^2 - 1}$
δ = rotation of a block subdivision with respect to the block immediately forward of it, radians
ϵ = complement of the wing leading edge sweep angle
ξ, η = integration variables
φ = velocity potential

Superscripts

- based on the geometry of the working-wing

Subscripts

RH = right-hand semiplanform
LH = left-hand semiplanform

gram. The size of the aerodynamic matrix is limited only by the storage capacity of the computer. The Convair program for the IBM-704 computer can calculate up to a 12,000 element matrix. It is believed, however, that for most aeroelastic analyses a 50 block per semiplanform to 50 pressure point solution of 5,000 element count is adequate.

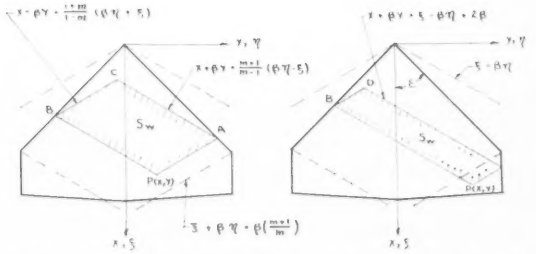


Fig. Ia. Details and limits of integration (subsonic leading edge).

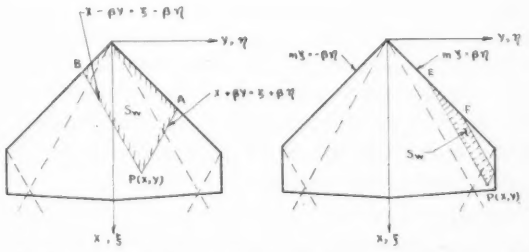


Fig. Ib. Details and limits of integration (supersonic leading edge).

For the subsonic leading edge solution only the region one integration area of Evvard[2] is considered. As noted by Etkin and Woodward[1] this approximation is satisfactory for $m \geq 0.4$.

Analysis

General Background

The well-known linear potential equation of steady, isentropic, supersonic (*Continued on page 76*)

Meteorology

Weather—

Luis de Florez, FIAS

Rear Adm. de Florez (USNR Ret.) is an Engineer, Inventor, and Aircraft Pilot who has distinguished himself in many fields of engineering and science. He holds seven decorations—among them the Collier Trophy (awarded in 1943 for development of training simulators) and the Navy's Distinguished Flying Cross—and next year will observe 50 years of active flying. While a Freshman at MIT, Adm. de Florez built airplane models and gliders and succeeded in measuring the thrust in flight of a Wright biplane for a graduation thesis. He began to fly in that year (1912); today, he pilots his own twin-engined amphibian and is qualified in all types of USN aircraft, including helicopters and jets. His interest in weather control and forecasting stems from his long years as an active airman.

SINCE THE VERY BEGINNING of our national existence, we the American people have traditionally fought and overcome Nature's forces at every hand, yet we display the same fatalism and resignation about the weather that our remote ancestors did in the Stone Age. We do not seem to realize that by subjecting the problem of weather control to an attack equal in magnitude and quality to that which brought about our great discoveries in the fields of flight, nuclear power, chemistry, medicine and other disciplines, we can expect results of equal, if not greater, value. Despite the enormous benefits which would accrue from research leading to weather control, we have not seen fit to tackle the work involved with the same determination and audacity that we have shown in harnessing nature in other ways, with consequent lack of progress.

Perhaps the greatest obstacle in the way of controlling the weather is our attitude of mind which appears to embody a combination of three major factors:

(1) A lack of sense of proportion concerning what is important to our existence.

(2) A form of mental block inherited from countless generations of peoples awed and cowed by the elements and powerless to do anything other than protect themselves against them.

(3) Incomplete realization of the tremendous advances and power of science and technology of our time.

At this period in our history when we are bending every effort to conquer space and solve the great problems of space travel, we seem to have bypassed any serious thought of reshaping our own atmospheric conditions which basically affect existence on our own home grounds.

This is not to imply that we should curtail our space programs in any way, but since our atmospheric conditions constitute the greatest single factor controlling the existence of life on earth, our effort to reshape the conditions of "inner space" to our immediate benefit should at least accompany the attempts to master "outer space" for the future.

Man—and countless other forms of life—breathes the atmosphere, feeds on the products that grow in it, and conforms to the climate it produces.

The incredibly complex movements of the atmosphere, caused by the absorption of solar energy and rotation of our globe, determine, in the main, our weather and our climates. In turn, our climates and weather determine the living conditions, the consequent evolution of species and the characteristics of peoples.

Take It or Make It

The de Florez Company

IT IS PARTICULARLY APPROPRIATE that these imaginative comments on meteorology by a distinguished American be published at a time when our national program in the atmospheric sciences is under thoughtful review by the Executive and Legislative Branches of the Government, working in consonance with the scientific community.

No pleader for parochial interests, Admiral de Florez has effectively combined some mind-stretching thoughts on the implications of large-scale weather control with a perceptive analysis of the orderly measures that must be taken to mount a sound effort commensurate with the potential importance of the problem.

By emphasizing the intrinsic values, as opposed to the competitive values, of an adequate research program to explore the scientific feasibility of modifying weather and climate, Admiral de Florez has placed the problem in proper perspective. Much could be gained, little could be lost, by acting on his thoughtful recommendations.

— Thomas F. Malone, *President*
American Meteorological Society

Only man, out of all species of life, has learned to adapt himself artificially to all kinds of weather. He has discovered fire, invented clothing, habitations, refrigeration and pressurization—in short—everything he has needed to exist anywhere on the earth, and possibly beyond it. Homo sapiens, a relatively weak and hairless creature, has survived and populated the earth, harnessed nature's energy and rules the animal kingdom, while many more powerful and formidable species have become extinct, through lack of intellect.

Man's brilliant accomplishments, his dedication to exploration and adventure, his ingenuity, courage and determination are often dimmed by his shortcomings in accustoming himself to his newly acquired power. Nevertheless, let us not underrate this magnificent adolescent of our world's species of life because he sometimes makes mistakes in wielding his relatively sudden mastery over nature. As yet, his genius has no limit and he can and will achieve control of weather (*Continued on page 55*)

Approximations in

John V. Breakwell

Lockheed Aircraft Corporation

In a recent paper, Lu Ting[1] indicates that the methods used by Dommasch[2] and Barron[3] yield essentially optimum trajectories in a certain context. The computation in the Dommasch-Barron solution is slightly simplified by neglecting the Lagrange multiplier associated with the kinematic constraint involving altitude rate. It would be interesting to determine whether this neglect is generally insignificant in flight optimization problems.

This note therefore proposes to draw a numerical comparison in an idealized problem wherein the computations are simple enough not to require machine computation. The comparison will be between (1) an orthodox solution involving the usual Lagrange multiplier associated with a kinematical restraint, and (2) an unorthodox solution in which this particular multiplier is treated as identically zero.

Before proceeding to the choice of idealized problem it is instructive, perhaps, to consider the Lagrange multiplier as used in a recent paper:[4] In maximizing some "payoff" function M of trajectory end-values the maximum obtainable M is automatically, although not explicitly, a function M^* of initial values. The value at time t of the Lagrange multiplier λ_i associated with a physical variable x_i is just $\partial M^*/\partial x_i(t)$ where M^* is now regarded as a function of the values $x_i(t)$ at time t, regarded as a starting time. In the case of the "kinematic variable" h, the altitude, whose time-rate is given by a kinematic rather than a dynamic equation, we certainly expect the payoff in many problems to be sensitive to initial altitude, so that $\lambda_h = \partial M^*/\partial h \neq 0$. This is especially true if air drag is a significant feature of the problem.

Let us therefore choose for our comparison the problem, treated originally by Tsien and Evans[5] and subsequently by Leitmann,[6] of determining thrust history in a vertical ascent so as to maximize the altitude H reached by a rocket. As in Refs. 5 and 6 let us assume that gravity g is independent of altitude, and the drag force varies quadratically with speed and decreases exponentially with altitude.

The rates of change of altitude h, speed v, and mass m are:

$$\left.\begin{aligned} \dot{h} &= v \\ \dot{v} &= [T - D(h, v)]/m - g \\ \dot{m} &= -T/c \end{aligned}\right\} \qquad (1)$$

where c is a constant "exhaust velocity," T the thrust to be determined as a function of time, and D the drag force, which is assumed to have the form:

$$D = Wv^2e^{-\alpha h} \qquad (2)$$

where W and α are constants.

If m_1 is the burn-out mass and if h_1 and v_1 denote the altitude and speed at the moment t_1 when fuel is exhausted, the altitude H may be determined as a function $H(h_1, v_1)$ of h_1 and v_1, as well as of W/m_1, α, g, by integrating Eq. (1) with $T = 0$ and $m = m_1$

Dr. Breakwell is a Staff Scientist in Applied Mathematics of the Research Branch of the Lockheed Missiles and Space Division where he conducts mathematical studies of satellite orbits. Dr. Breakwell received his B.A. in 1939 from Oxford and his Ph.D. (mathematics) in 1947 from Harvard. Prior to joining Lockheed in 1957, he was associated with North American Aviation, Inc., where he was concerned with reliability studies as well as missile stability and trajectory optimization. He holds memberships in AAS, AMS, IMS, ORSA, SIAM, and Sigma Xi.

Flight Optimization Problems

A numerical comparison is made in an idealized problem utilizing simple computations to derive an orthodox solution involving the usual Lagrange multiplier and an unorthodox solution in which the multiplier is treated as identically zero.

up to the point where $v = 0$. The relation which defines $H(h_1, v_1)$ implicitly (cf., Ref. 6) is:

$$(\alpha v_1^2/2g)\, e^{-(2W/\alpha m_1)\, e^{-\alpha h_1}} = \int_{(2W/\alpha m_1)\, e^{-\alpha H}}^{(2W/\alpha m_1)\, e^{-\alpha h_1}} e^{-z}(dz/z) \quad (3)$$

Our problem is, given initial mass m_0 and zero initial speed and altitude, to determine $T(t)$ up until burn-out t_1 so as to maximize $H(h_1, v_1)$.

1. Orthodox Solution

As in Ref. 4, we introduce Lagrange multipliers λ_h, λ_v, λ_m, associated with h, v, m. Their time-rates are given by: $\dot{\lambda}_h = -\partial F/\partial h$, $\dot{\lambda}_v = -\partial F/\partial v$, $\dot{\lambda}_m = -\partial F/\partial m$, where F, in accordance with Eq. (1), is given by:

$$F \equiv \lambda_h v + \lambda_v \{[T - D(h, v)]/m - g\} - \lambda_m T/c \quad (4)$$

$$\left.\begin{aligned} \text{Thus;} \quad \dot{\lambda}_h &= (\lambda_v/m)\ (\partial D/\partial h) \\ \dot{\lambda}_v &= \lambda_h + (\lambda_v/m)\ (\partial D/\partial v) \\ \dot{\lambda}_m &= (\lambda_v/m^2)\ (T - D) \end{aligned}\right\} \quad (5)$$

The Lagrange multipliers must satisfy the following end-conditions:

$$\left.\begin{aligned} \lambda_h(t_1) &= \partial H/\partial h_1 \\ \lambda_v(t_1) &= \partial H/\partial v_1 \end{aligned}\right\} \quad (6)$$

Now, subsequent to burn-out, h must increase and v decrease in such a way that the function $H(h, v)$ remains constant. From Eq. (1), with $T = 0$, it follows thus that $(\partial H/\partial h)\, v - \partial H/\partial v \{[D(h,v)/m_1] + g\} = 0$. In particular, because of Eq. (6), the values $\lambda_h(t_1)$ and $\lambda_v(t_1)$ must be related by:

$$v_1\lambda_h(t_1) = \{[D(h_1,v_1)/m_1] + g\}\lambda_v(t_1) \quad (7)$$

The optimum thrust $T(t)$ at any instant must be such as to maximize the F in Eq. (4). This means that T should be the maximum possible thrust, say $T_{\max}$, whenever $(\lambda_v/m) - (\lambda_m/c) > 0$, but that T should be zero if and whenever $(\lambda_v/m) - (\lambda_m/c) < 0$. If during any period the optimum thrust level is some intermediate level, we require during this period:

$$(\lambda_v/m) - (\lambda_m/c) = 0 \quad (8)$$

Differentiating w.r.t. time and using Eqs. (1) and (5), we find during this period:

$$\lambda_h = (\lambda_v/m)\ \{[\partial D(h,v)/\partial v] + [D(h,v)/c]\} \quad (9)$$

Assuming that this period lasts until burn-out, we find from Eqs. (6) and (9) that

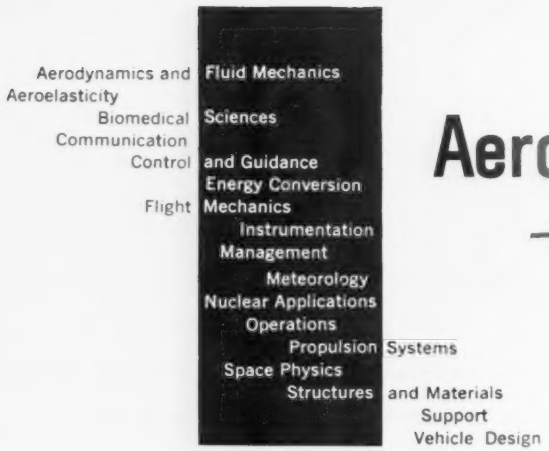
$$\frac{v_1}{m_1}\left[\frac{\partial D(h_1,v_1)}{\partial v_1} + \frac{D(h_1,v_1)}{c_1}\right] = \frac{D(h_1,v_1)}{m_1} + g \quad (10)$$

On the other hand, it follows from the forms of Eqs. (2) and (4), together with the fact that the values in Eq. (6) are certainly positive, that λ_h and λ_v are positive at all times. This is also clear from their interpretation. At $t = 0$, then, the left member of Eq. (9) is greater than the right member (which vanishes), and hence the left member of Eq. (8) is decreasing at $t = 0$. The ascent must therefore begin with a period during which $T = T_{\max}$.

Differentiating Eq. (9) w.r.t. time and making use of Eqs. (1), (5), and (9), we obtain during the period of intermediate thrust.

$$\frac{\partial D}{\partial h} = v\frac{\partial^2 D}{\partial v^2} + \frac{\partial^2 D}{\partial v \partial h} + \frac{v}{c}\frac{\partial D}{\partial h} + \frac{2\dot{v} + g}{c}\frac{\partial D}{\partial v} + \frac{\dot{v} + g}{c^2} D \quad (11)$$

(*Continued on page 80*)



Aerospace Technology

–as seen by the panels

Aeroelasticity

It Still Poses Important Problems

R. L. Bisplinghoff, FIAS

The author is Technical Consultant to *Aerospace Engineering*, Professor of Aeronautics and Astronautics at M.I.T., and Chairman of the IAS Aerospace Technology Panel on Aeroelasticity.

IN THIS AGE of space achievement, the continuing importance of aeroelasticity is rarely emphasized as much as it was recently when NASA pilot, Joe Walker, flew the X-15 at speeds in excess of 3,000 mph and Navy pilots, Commander P. L. Sullivan and Lt. B. W. Witherspoon, flew a Sikorsky Twin Turbine HSS-2 helicopter to a record speed of 174.9 mph over a 100 km closed course. The two achievements were especially noteworthy in that they involved types of aeroelastic systems which will be highly important in the future. The heated structure of the X-15 typifies the important future problems of lifting re-entry vehicles and supersonic transport airplanes. The Sikorsky HSS-2 emphasizes the fact that forward speeds of rotating aeroelastic systems have increased remarkably in the past few years, and will continue to increase well beyond their present level.

It is worthwhile to review occasionally where we stand with respect to the kind of aeroelastic problems posed by these two widely different types of flight vehicles. The imposing term "aerothermoelasticity" has been coined to designate that branch of aeroelasticity which is associated with heated structures. Generally speaking, at least for moderately heated structures, this branch of aeroelasticity involves the same approach as for cold structures with appropriate corrections for loss of stiffness and deformations due to heating effects. For some time there were questions as to whether other new lifting surface instabilities may be produced as a result of coupling between the thermal and aeroelastic systems. For example, temperature gradients throughout the thickness of a wing produce deformations of the wing; or extremely rapid changes in temperature distributions may even induce vibrations. Such couplings, however, have been found to be too weak to be important in most cases and they provide only modifications to the usual aeroelastic instabilities without introducing new phenomena not heretofore experienced. The successful handling of aerothermoelastic problems resolves itself therefore into the usual pattern; a correct understanding of the elastic properties of the heated structures of interest and of the aerodynamic forces in the appropriate speed range. There is a problem, however, which is unique with supersonic flight vehicles, and which is profoundly aggravated by the presence of aerodynamic heating. This is the problem of surface skin panel flutter. Experiments have shown conclusively that flutter of surface skin panels can exist. Failures of panels on actual flight vehicles have been experienced which were traced to a flutter phenomenon. Panel flutter differs from the more conventional lifting surface flutter in at least two important respects: first, it is entirely a supersonic phenomenon; and second, structural nonlinearities associated with the lateral deformation of panels tend to limit strongly the flutter amplitudes. The latter limitation often causes the modes of structural failure to be those peculiar to fatigue rather than explosive fracture of the skin surface. Many valuable contributions have been made to the theories of panel flutter. At the time of this writing, however, there is a lack of carefully conducted experiments with which to compare these theories. More research is required in this important area in order to place panel flutter analyses within the same category of acceptance as other aeroelastic analyses.

Rotary wing vehicles provide many aeroelastic

problems which are imperfectly understood. The basic differences between a rotor blade and a high aspect ratio wing lie largely in the presence in the former of centrifugal force and variable velocity fields. Although the centrifugal force field introduces some complexities in aeroelastic analyses, the underlying physical principles are known. The variable velocity field, however, introduces aerodynamic difficulties which are very poorly understood, and approximate empirical methods must be employed. A more thorough fundamental understanding of the aerodynamics of rotary wings is the principal requirement for improvements in their aeroelastic analyses

As long as man continues to fly vehicles within the atmosphere, aeroelastic phenomena will pose important problems which must be overcome by designers. Flight vehicles typified by the X-15 and the HSS-2 are representative of circa 1960. There will be others in 1970.

✦ ✦ ✦

Communication

Will the U.S. Be First in Space?

Peter C. Sandretto, Brig. Gen., USAFR

General Sandretto is Deputy Group Executive of International Telephone and Telegraph Corporation's U.S. Defense Group, and Chairman of the IAS Aerospace Technology Panel on Communication.

THE UNITED STATES has committed itself to the principle that space should be used for peaceful purposes. One of the most obvious of these uses of space is for communications. The use of space for this purpose has been occupying the attention of the journalists for some months and the purpose of this article, therefore, is an attempt to state what the issues are so that the reader may obtain a picture of purpose and the status of this project.

Communication via satellites is advantageous when communication is over long distances; that is, at present no one has suggested that there is an advantage in using the satellites where the distances are short. At present, there has been installed some underwater cables for international telephone communications; however, most of the world's intercontinental telephone circuits are via high-frequency radio. The system operates as follows: In the United States, there is a radio station operated by the American Telephone and Telegraph Company which connects to the AT&T long-lines complex. In foregin countries, there are similar high-frequency radio stations which are often but not always operated by Post Office departments of each (the International Telephone and Telegraph Company operates these stations in six countries). These stations connect to the telephone systems of the countries' Post Office departments' telephone-operated systems. In other words, to furnish communications to the personnel at both ends, there is required an extensive network of telephone sets in the homes or offices of the various individuals which must be connected by an extensive and expensive network of telephone line and switching systems. The radio stations are only one element in the overall communications system. These radio stations obtain long-distance transmission by bouncing their emitted waves from a layer located some 90 miles above the earth and referred to as the ionosphere and sometimes by the more formal name of the Kennely-Heaviside layer. In the satellite's system, the ionosphere is replaced by an earth satellite. International record communications (Teleprinter, etc.) in the United States as contrasted with international telephony are carried on by several companies. These companies very largely utilize both radio and cable for their purpose and, in addition to owning their transmission facilities, sometimes rent a telephone channel in the telephone cable and utilize this single channel for many Teleprinter channels.

One may well wonder what is the purpose of replacing the ionosphere with a satellite. It will still be necessary to have radio stations at the terminals of the two communicating countries and it will still be necessary to have the extensive telephone lines and an elaborate and expensive switching system connecting each person who desires to talk. What, therefore, is the purpose in using satellites? What can these satellite systems do which is not now accomplished by the present radio stations bouncing their transmissions from the ionosphere rather than from a satellite with its added cost of being placed into orbit? The advantage in using satellites for bouncing radio signals from one point to another over using the ionosphere for this purpose is that the satellite permits use of the very and ultra high frequencies. These frequencies normally travel only line-of-sight and cannot be bounced from the ionosphere. The use of these frequencies offers two advantages for radio communication. First, they are very free from static, and second, they permit large bandwidths. In order to transmit voice, the bandwidth of 3,500 cycles is normally required, but in order to transmit television, bandwidths of the order of 4 million cycles are required. The high-frequency radio signals bounced from the ionosphere normally are capable of providing only up to 8 voice channels (about 24,000 cycles) and at the same time are subjected to the vagaries of ionospheric fading and static. Thus, it is seen that the satellite as a bouncing device permits

the use of frequencies that can very readily provide bandwidths of many millions of megacycles. These millions of megacycles, therefore, permit many, many voice channels and television transmissions. Our national government is particularly interested in satellites as a means of broadcasting via television events in this country to foreign countries. The events would then be retransmitted over the local broadcasting networks.

There are three types of satellites being considered for voice and video communications purposes. These are as follows:

1. Synchronous orbit active satellites.
2. Nonsynchronous orbit (low-altitude) active repeater satellites.
3. Nonsynchronous passive satellites.

An excellent discussion of these three types of satellites together with the advantages of each appears in an article by Leonard Jaffe in the February 1961 issue of AEROSPACE ENGINEERING. It is not intended to repeat Jaffe's discussion here; however, a brief description may be of interest. In the synchronous orbit, active satellite, it is intended that three satellites be placed above the earth at altitudes of 22,300 miles. In each of these satellites, there must be located amplifiers which will receive the signals from one country and retransmit them. There is no problem in sending a signal to the satellite because there is practically no limit to the power that can be utilized on the ground, but in transmitting from the satellite to the second point, there is a difficulty because of the limited amount of power that can be made available in the satellite. This type of satellite also must be fitted with the equipment which will be capable of holding the satellite over a single point.

The second type of satellite is the one which has been proposed by the AT&T. This satellite, like the first one, utilizes an amplifier which receives signals from one ground point and a transmitter which sends it out to the second ground point. However, the distances at which it is intended to orbit these satellites is only 2,000 miles; that is, approximately one tenth the distance of the synchronous satellites. On the one hand, the use of these satellites makes the problem of sending them into orbit easier. On the other hand, the satellite is moving continuously and, therefore, more than one must be used. AT&T is proposing the use of some 20 satellites for this purpose. It is claimed that the additional satellites will make for increased reliability.

The third type of satellite is exemplified by the large reflective balloon called Project Echo that was sent up by NASA in 1960. With a large reflective balloon, there is no amplifier or transmitting equipment required in the satellite. It is necessary that the transmitting power on the ground be great and, of course, a number of these satellites must be placed in space if communications are to be continuous since they are continuously rotating about the earth.

Now the question arises as to the mechanism to be utilized to bring into being communications via satellite and to do so as quickly as possible. To this end, there have been filings before the Federal Communications Commission (FCC). During the week of May 1st, filings were presented by the American Telephone and Telegraph Company, General Telephone & Electronics Corporation, International Telephone and Telegraph Corporation jointly with American Cable & Radio Corporation, Lockheed Aircraft Company, the Radio Corporation of America jointly with R.C.A. Communications, and Western Union Telegraph Company. In the filings, there was virtual unanimity that the ownership of these communication systems should be private via a joint company. Further, the filings agreed that satellite systems should be available to all common carriers on a nondiscriminatory basis. There was a difference of opinion as to whether ownership in the joint company should or should not be limited to common carriers. On May 24th, the FCC issued a report stating that a joint venture satellite communication system owned entirely by International Communications Common Carriers appears to be the instrument best suited to promote development of international communications via satellites.

It would have appeared that with the aforementioned action, the United States was now in a position to establish commercial communications via satellite. Such a condition, however, was not to be. The Justice Department objected strongly to the said plan and expressed concern over the possibility of AT&T's domination. Meetings were held between the FCC, Justice and State Departments, NASA, OCDM, and the President's Science Advisory Committee to discuss the problem. President Kennedy then asked the National Aeronautics and Space Council to study the issues and recommend a national policy.

✦ ✦ ✦

Operations

V/STOL Worries Lie Ahead

Benjamin S. Kelsey, Brig. Gen., USAF (Ret.), FIAS

General Kelsey is Director—Transportation Research Office of Booz-Allen Applied Research, Inc., and Chairman of the IAS Aerospace Technology Panel on Operations.

WITH THE FLIGHT demonstrations of several different configurations of V/STOL aircraft and with the

(*Continued on page 81*)

Adventures in Engineering

History's Most Elusive Paper Cup

George Blackburne

Mr. Blackburne is a Design Specialist in the Space Systems Division, Lockheed Missile and Space Company, Van Nuys, Calif. He was graduated with a B.S. degree in engineering in 1935 from the U.S. Military Academy at West Point, to which he was appointed while studying at Rensselaer Polytechnic Institute. As civilian ammunition designer for the Ordnance Corps during the Korean War, he worked on warheads, pyrotechnics, and fuses. He has been active in missile development since 1956, having made contributions to Atlas, Redeye, and Polaris, and to Satellites Midas and Samos.

THE POLARIS PROGRAM had a requirement for a paper recording cup to be used in the Launch Success Indicator (LSI), a device assembled into the spline of a Polaris Launch Test Vehicle to record its attitude throughout a compressed-air launch from a submerged submarine.

When the LSI design was approved as final and the recording cup parameters determined, there were only three weeks left for the development of the recording cups. Far worse, from a financial point of view, was the fact that only from 80 to 100 cups would be needed to meet all the known needs for the first year. This made the cost per cup prohibitive if standard methods of manufacture were used. In addition, the time required by the paper cup industry to make molds, etc., precluded their making the cups in the normal manner if the schedule was to be met.

These problems were solved by making the cups using vacuum-mold techniques. Since recording cups made of plastic could not be used, readily available paper was tried. Initially, the many types of paper normally found around research laboratories were tested experimentally—none worked. Eventually, the area of search was enlarged to include photographic laboratories. Complete success was finally achieved using 100 percent rag, undeveloped, standard photographic paper. Microscopic examination of this paper later revealed that possibly the silver emulsion on it never completely solidifies under the outer crust. As a result, this particular paper may never completely dry on the shelf. It seems reasonable to assume, therefore (strictly from an academic point of view), that this accounts for the excellent results achieved with this paper whereas all other types of paper failed.

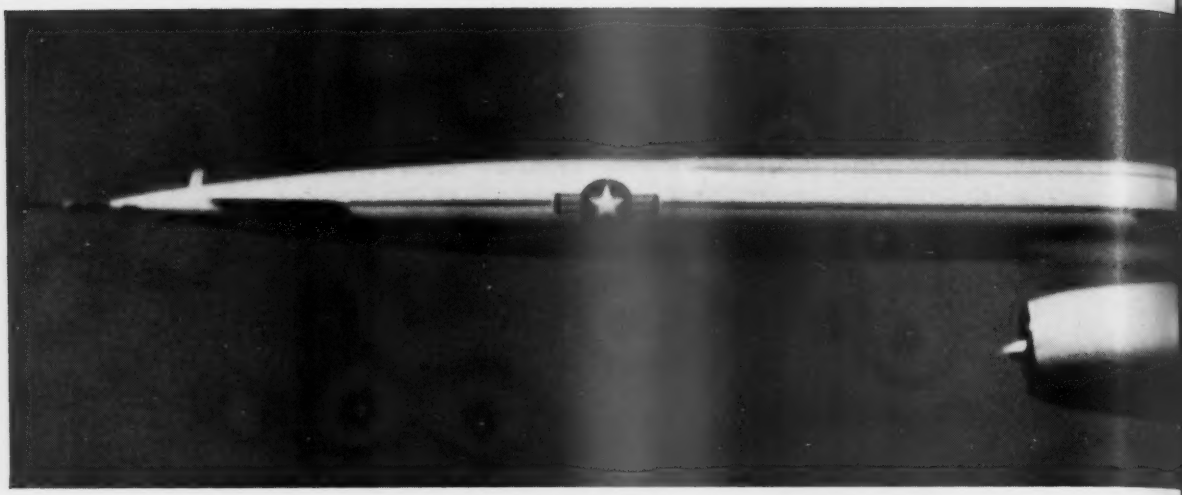
The actual forming process is as follows: Sheets of this photographic paper are soaked for approximately 30 min in warm water. A sheet is then placed in a 10-in. round frame and a weighted rubber ball placed at the center. Thirty minutes of this prestretched the paper into a dished-cup shape. The ball is then removed and the still wet paper is vacuum formed down onto an aluminum mold preheated in an oven to 170°F. This operation partially dries the paper. A male mold is immediately placed on top of the paper while the paper is still under vacuum. Both molds, with the paper sandwiched between, are then subjected to 2,000 psi in an arbor press and heated to 240°F. The paper is thus pressed and completely dried in this final operation. No draping (overlapping) at the edges occurs and the resultant cups are stiff and firm.

Success of the initial process was such that additional refinements were possible. An "O" ring groove was put around the outside of the recording cup by grooving the female die and placing a tourniquet around the outer surface of the wet paper while in the heated arbor. Draping did occur in the outer area but this did not affect the working surface inside the cup.

Later, when the cups were used, it was found that when the spark from the electronics package became weak the performance of the cup could be improved if it was sprayed with a commercial carbon compound and then coated with a mist of white lacquer to protect the carbon. "Go" and "No Go" sections on the cup were achieved by masking "No Go" areas prior to spraying. It seemed there was no end to the refinements possible, but our needs had been met; the cups were ready on schedule.

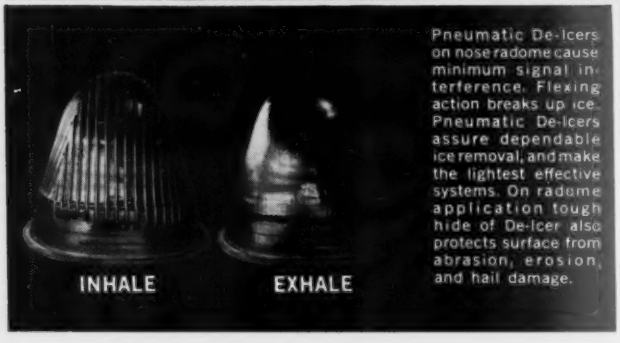
The experimental costs of developing the process

(*Continued on page 82*)

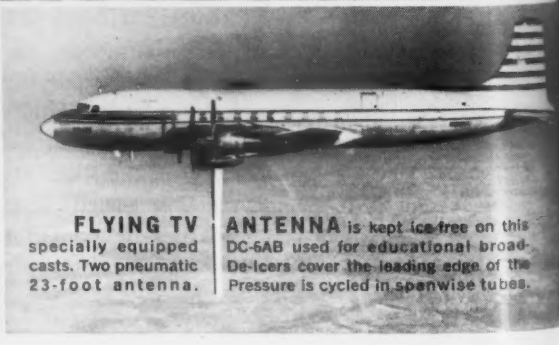


B.F.Goodrich develops versatile systems for ICE PROTECTION

HIGH PRESSURE PNEUMATIC DE-ICERS equip the wing and tail leading edges of Lockheed C-140 JetStar. System was chosen for light weight and simplicity.

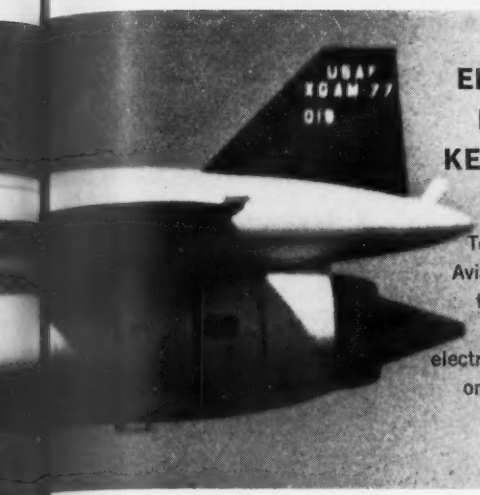


Pneumatic De-Icers on nose radome cause minimum signal interference. Flexing action breaks up ice. Pneumatic De-Icers assure dependable ice removal, and make the lightest effective systems. On radome application tough hide of De-Icer also protects surface from abrasion, erosion, and hail damage.



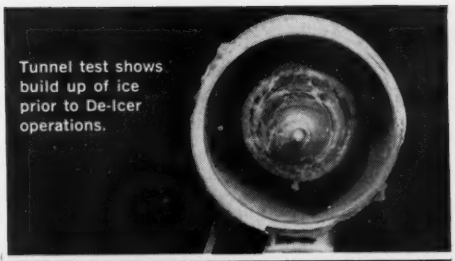
FLYING TV specially equipped casts. Two pneumatic 23-foot antenna.

ANTENNA is kept ice-free on this DC-6AB used for educational broad- De-Icers cover the leading edge of the Pressure is cycled in spanwise tubes.

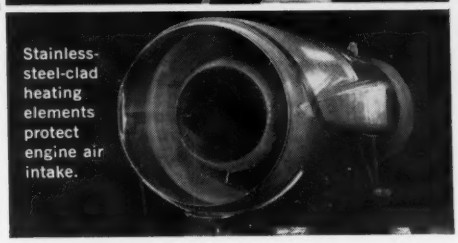


ELECTRO-THERMAL DE-ICER SYSTEMS KEEP "HOUND DOG" NOSE WARM

To keep this North American Aviation missile's engine ready for instant launching despite freezing conditions, BFG electro-thermal units are installed on the nose cone, supporting struts and ram air probes.



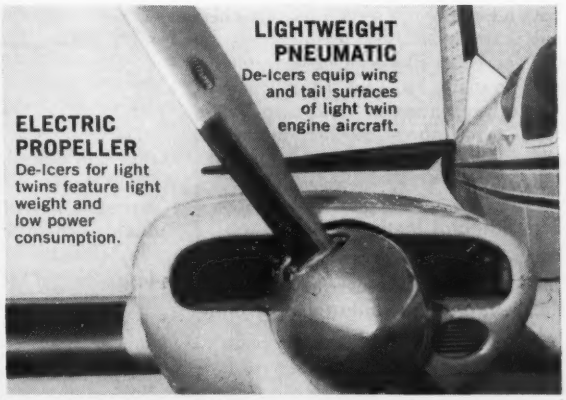
Tunnel test shows build up of ice prior to De-Icer operations.



Stainless-steel-clad heating elements protect engine air intake.

Since introducing the first pneumatic De-Icers for aircraft over thirty years ago, B.F.Goodrich has developed a broad capability in ice protection systems: *Pneumatic De-Icers* are used on high performance aircraft like the Lockheed C-140 JetStar...and designed as lightweight systems for small twins. *Metal Clad Electro-Thermal De-Icers* can be adapted to airfoil shapes, and in many cases can serve as structural members. *Heated Rubber* is adaptable to fit complex curves or odd shapes for localized heating. *Reinforced plastic parts*, integrally heated, are available for applications not subject to severe abrasion. Whatever your requirements in eliminating or controlling ice bring them to BFG...the leader in De-Icing. For information contact *Dept. AS-9, B.F.Goodrich Aerospace & Defense Products, a division of The B.F.Goodrich Company, Akron, Ohio.*

"HAIL-SAFE" DE-ICING is provided on empennage of General Dynamics/Convair 880 by BFG Cladheat electro-thermal De-Icers. Stainless steel skin withstands abrasion from rain, dust, even hail at high cruising speeds. Six-foot Cladheat sections are bonded to leading edges to form a smooth, integral airfoil.



LIGHTWEIGHT PNEUMATIC De-Icers equip wing and tail surfaces of light twin engine aircraft.

ELECTRIC PROPELLER De-Icers for light twins feature light weight and low power consumption.

HEATED RUBBER bonds securely to complex curves and odd shapes as well as flat surfaces. Integral electrical heating elements control ice formation in areas such as air intakes and cowls, or provide heating for power units.

B.F.Goodrich

aerospace and defense products

Optical Tracers (Continued from page 9)

ments of density in the atmosphere above about 120 km have been accomplished by contaminant releases.

Missile Loading and Guidance

The effects of wind upon guidance of high-velocity missiles are well known. Sounding rockets which have no provisions for guidance are launched only after careful measurements are made by a balloon to account for the winds properly. For guidance these measurements are usually adequate. However, the forces exerted upon a missile by varying winds may be quite severe and contribute to breakup. Wind shears or wind velocities which change appreciably over short height intervals produce the worst buffeting of this type. At present it is not possible to study small-scale wind structures by balloon techniques because of balloon inertia, or the inability of the balloon to assume the local wind velocity instantaneously at each height. The wind profile obtained by balloons represents only average wind velocities, with all small-scale structures smoothed out. More precise measurements of the desired smaller scale are possible by photographing a trail of particulate matter or spheres of condensed vapor released into the atmosphere intentionally or as the by-product of a missile exhaust.

Experimental Method

There follows a discussion of the methods used to produce contaminant clouds in order to study them by optical means. In addition to optical methods of study, some contaminants produce considerable ionization and may be detected and followed by radar techniques. The details and significance of this important work have appeared in numerous publications.[3]

Simple mechanisms have been employed to release contaminants, depending upon the particular contaminant and the purpose of the experiment. Usually some sort of timer is employed to activate the release at the desired time and altitude. If the contaminant is a gas at room temperature, or can be carried in heated containers under conditions where it remains gaseous, a simple valve opening or explosive destruction of the container is sufficient. In some cases, the contaminant may exist in a chemical form which is unstable or may be mixed with other constituents so that ignition of the mix will release the contaminant in the desired atomic or molecular state. A third mechanism which has been employed extensively for releasing the vapor of alkali metals consists of a thermite mixture of Fe_2O_3 and aluminum powder which releases heat when ignited.[1] The alkali metals may be packed in the thermite as pure metals and are vaporized by the released heat. For still other applications, chemicals are released which utilize the water vapor present in the atmosphere to generate droplets.[4]

Ground measurements of the vapor trail may be obtained if light from the contaminant cloud is bright enough to be photographed. The photographs can be reduced and studied by various techniques, and it is frequently found that a vast amount of data is obtained beyond that for which the experiment was initially designed. Fig. 1 shows a series of photographs taken from two observing sites at various times after the release of sodium vapor. If triangulation is to be performed, two or more separate observing sites, separated by a suitable baseline are required, and the exposures at the various sites should be performed synchronously. Fig. 2 shows a bank of cameras designed to photograph the sodium vapor releases. The cameras operate electrically, and exposures are determined by a control box which is adjusted to WWV timing signals to assure simultaneity at all sites. The control box and allied switches record the time, azimuth angle, elevation angle, and other information for each exposure beside the photographed image. The cameras are fitted with various optical filters to isolate specific wavelengths of light scattered from the clouds.

For very weak light intensities or when background light is excessive, detection may be accomplished with photometers equipped with photomultiplier detectors and very narrow bandwidth filters. By means of special spectrographic equipment, the line width of the scattered emission can be measured to determine temperature.

Fig. 2. Five electrically operated cameras and allied field equipment for photographing sodium trail releases.

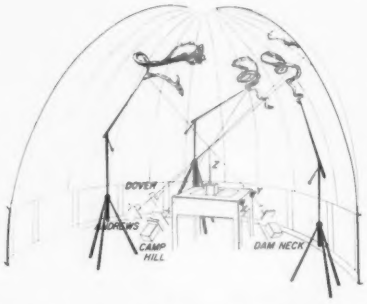


Fig. 3. Analog device used for data reduction.

Data Obtainable

By triangulation methods, photographs made at the same time from two or more sites are used to obtain the coordinates of numerous points throughout the cloud. For the filament releases shown in Fig. 1, points are selected which are separated about one half a kilometer in height and along the central line of the filament. Similar sets of photographs taken at different times are then reduced in the same manner. Winds are derived from the change in cloud position as a function of time. The filaments in Fig. 1 extend from 80 km to over 200; the number of height intervals considered is more than 100; the number of positions to be determined from a single experiment is well over 1,000. Some form of mechanical or computational assist is necessary to handle the data. Fig. 3 shows an anolog device used for this purpose. Photographs are projected from specially built projectors in the exact angular dimensions and orientations existing at the observing site. The projectors are situated so that, from a specific point along their optical axis, the relation 0.2 in. in the scale model equals 1 km in the field. After proper orientation and alignment, position measurements may be made very simply.

Cloud growth as a function of time is determined by a densitometer of the photographic negatives. By the choice of a suitable theoretical model for the expansion, these measurements may be used to determine the coefficient

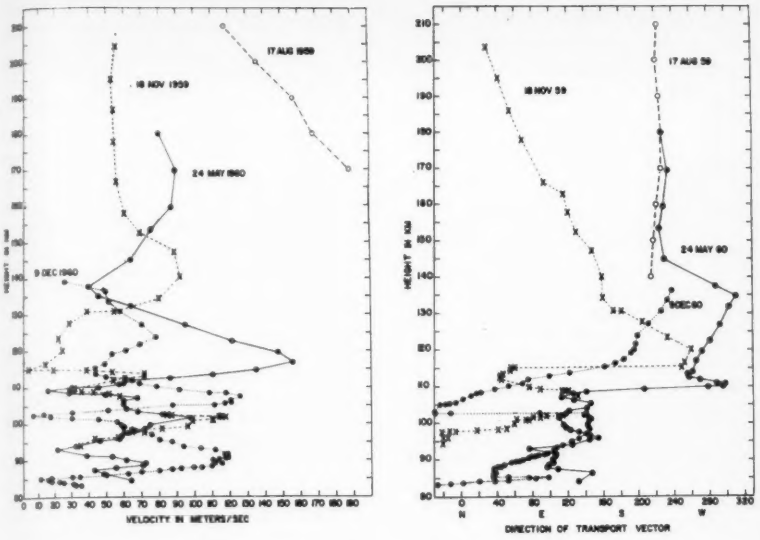


Fig. 4. Mea ured wind profiles.

of diffusion. Cloud intensity as a function of time may be determined from the densitometered photographs, or may be measured photometrically in the field at the time of the experiment. For a cloud released at a point in the atmosphere and expanding spherically, it can be shown that the surface brightness near the cloud edges is given by

$$B = (K/4Dt)e^{-(r^2/4Dt)}$$

where B is brightness per unit area, D is coefficient of diffusion, t is time measured from release time, r is distance measured from cloud center, and K is a constant which involves the amount of material released. By measuring B, r, and t near the cloud edges for a series of photographs, the appropriate D may be determined.

Significant Achievements

Among the achievements obtained by optical observations of contaminant releases, the most important specific results may be summarized as follows:

Wind profiles: Fig. 4 shows some of the results of the methods for determining wind data.[5]

Molecular diffusion coefficients: The coefficient for diffusion of a contaminant gas through the atmosphere is a function of the atmospheric species and density and of the temperature. When measurements are made at a series of heights, relationships between density and temperature may be employed, along with the measured coefficients, to describe in some detail the density as a function of height. Fig. 5 shows some measured coefficients of molecular diffusion.

Turbulence characteristics: Below about 105 km, turbulence is noticeable from photographs of sodium filaments. These data are being used to determine the characteristics of atmospheric turbulence in these height regions and to attempt a better understanding of these phenomena.

Region of oxygen dissociation: NO vapor[6] and sodium vapor[7] have been released at night. Photochemical reactions release light which, when coupled with a theory of the reactions, yields significant data concerning the concentration of atomic oxygen and rather precise data concerning its relative distribution with height.

Density of atomic nitrogen: Light was observed from sodium vapor at night in the height region above 130 km to the extent of the filament at 180 km. No known photochemical reaction can account for this emission. It has been proposed that trace amounts of atomic nitrogen in its first metastable level can transfer energy to the sodium yielding the observed light. If verified by laboratory measurements, this may provide a tool for studying atomic nitrogen in the atmosphere.

Upper atmosphere temperatures: A release of sodium vapor at 370 km in December 1960 yielded a value of the coefficient of diffusion at that height. A temperature measurement was performed by Professor Blamont and his coworkers by observing the line profile. This represents the first temperature measurement at such heights.

Vertical transport rates: In numerous experiments, vertical velocities of a few meters per second have been determined. Too few such measurements have been made to establish a consistent theory or empirical relation. Additional measurements of vertical velocities are expected to provide essential data for

DYNAMICS ENGINEERS

Immediate openings for Structural Dynamics, Vibration, and Flutter Engineers to work on advanced present and future manned aerodynamic vehicles.

Graduate Engineers in Aeronautical, Mechanical or Applied Mechanics needed for:

Vibration Prediction
Structural Vibration Analysis
Dynamic Response Calculation
Oscillatory Aerodynamics

Specialists or Senior Engineers have excellent opportunities in the fields of vibration, dynamic analysis, structural response, and flutter. Openings available at all levels of experience and responsibility.

Experience in at least one of these fields, plus an advanced degree in AE, ME, or Applied Mechanics required.

Write: Mr. H. J. Bowman, Engineering Personnel, North American Aviation, Inc., Los Angeles 45, California.

All qualified applicants will receive consideration for employment without regard to race, creed, color, or national origin.

LOS ANGELES DIVISION

NORTH AMERICAN AVIATION

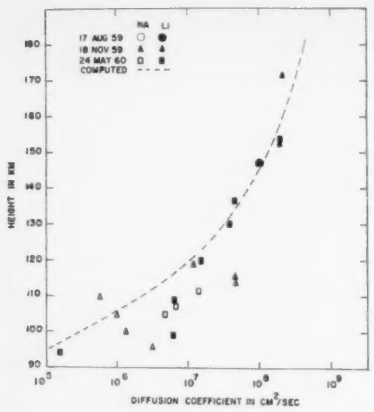


Fig. 5. Measured diffusion coefficients.

confirming or rejecting the theories of gravity waves and to define more clearly the effects of vertical mixing.

Optical beacons: The Soviets have released sodium vapor in deep space as a means of tracking their missiles. Experiments of this nature permit a very precise "fix" on the missile by telescopes capable of recording star background at the same time.

Characteristics of a gas expanding into a hard vacuum: In addition to the Soviet releases of an optically active material in space, United States sounding rockets have released sodium vapor and lithium vapor at 650 and 700 km, respectively. The expansions were photographed, and are presently being densitometered. Since the mean-free-path for collisions is several hundred km at these heights, the releases may be considered as occurring in a vacuum.

Conclusions

Contamination experiments are easily performed from a rocket standpoint. The primary measurements are made from the ground and may employ highly developed equipment which could not be fitted to a rocket. The experiments are relatively cheap and obtain independent measurements which in many cases provide the only known means of measurement. A few logical extensions of the method may be listed as follows:

(1) Lower altitude wind shears as described in the foregoing.

(2) Transport velocities of the ionization regions. In particular, the electrojet consistently observed over the equator.

(3) High-altitude global dynamics, residence times, and global wind structures.

(4) More detailed studies of turbulence, such as the photography of the turbulent expansion of a contaminant by very long focal length cameras.

(5) Study of winds in arctic regions to take advantage of the long twilights for extended observation. The time rate of change of the winds would be checked.

References

[1] Edwards, H. D., Bedinger, J. F., Manring, E. R., and Cooper, C. D., *Emission from a Sodium Cloud Artificially Produced by Means of a Rocket,* from "The Airglow and the Aurorae," Pergamon Press, London and New York, 1956, pp. 122–134.

[2] Connor, J. A., *Aerospace Nuclear Power Safety Considerations,* AEROSPACE ENGINEERING, May 1961, pp. 26–27, 58–61.

[3] Marmo, F. F., Aschenbrand, L. M., and Pressman, J., *Artificial Electron Clouds—I,* Planetary & Space Sci., Vol. 1, pp. 227–237.

[4] Langer, G., and Stockham, J., *High Altitude Tracking by Chemical Smoke,* J. Geophys. Res., Vol. 65, No. 10, Oct. 1960, pp. 3331–3338.

[5] Manring, E., Bedinger, J. F., and Pettit, H. B., *Some Wind Determinations in the Upper Atmosphere Using Artificially Generated Sodium Clouds,* J. Geophys. Res., Vol. 64, No. 6, June 1959, pp. 587–591.

[6] Pressman, J., Aschenbrand, L. M., Marmo, F. F., Jursa, A. J., and Zelikoff, M., *A Synthetic Atmospheric Chemiluminescence Caused by the Release of NO at 106 Km,* from "The Threshold of Space," Pergamon Press, London and New York, 1957, pp. 235–239.

[7] Bedinger, J. F., Manring, E. R., and Gosh, S. N., *Study of Sodium Vapor Ejected into the Upper Atmosphere,* J. Geophys. Res., Vol. 63, No. 1, March 1958, pp. 19–29.

✦ ✦ ✦

Modes of Failure of a Hypersonic Re-Entry Glide Vehicle (Continued from page 15)

and, thus, the stability boundaries. Figs. 1 and 2 show two points on the mission profile. In Fig. 2 spiral stability is not achieved without automatic controls; however, the long period for the spiral mode allows the pilot to control the vehicle readily. After 20 flights the accumulated strain changed the stability derivatives enough to exceed the oscillatory boundary as well as the spiral boundary. One might conclude that a larger initial cathedral in the wing would allow for the wing deflection effects and keep the aircraft within the oscillatory boundary. However, Fig. 1 shows another point on the mission. Note that the aero-thermal-elastic change to C_{l_β} will move the rigid point to the right for the flexible case which is more favorable for the spiral mode. Therefore, care must be exercised before making design changes; the full flight profile with and without augmented controls—rigid and flexible—must be analyzed. Refs. 4 and 5 show some more flexible changes to the stability derivatives, methods of calculating, and comparison with flight test.

The dynamicist is also concerned with the handling characteristics of the vehicle. The time to damp to 1/2 the amplitude vs. the longitudinal period and the time to damp to 1/2 the lateral mode amplitude vs. the bank angle to lateral velocity ratio are frequently considered. As the wings are reduced to low aspect ratios for high-speed flight, and the cruise altitude increases, the handling qualities become more critical (Figs. 15 and 16 from Ref. 6). Flexibility effects tend to push the vehicle further into the "unsatisfactory" region. Augmented controls are much more critical since they must do a bigger job for a vehicle whose speed is rapidly changing and is expected to be marginal without augmentation.

The dynamics engineer is also concerned with the steady-roll equations velocity at which directional and pitch divergence occurs. The equations from Ref. 7, simplified and assuming relatively small engine terms, are

$$p_0 = \pm\sqrt{\frac{c_{n_\beta} qSb}{I_y - I_x}} + \frac{I_{x_e} w_e}{2(I_y - I_x)}$$

for directional divergence boundary

$$p_0 = \pm\sqrt{\frac{-c_{m_\alpha} qS\tau}{I_z - I_x}} + \frac{I_{x_e} w_e}{2(I_z - I_x)}$$

for pitch divergence boundary

Since the largest contributor to the stability derivative C_{n_β} is the vertical tail (Ref. 8), the aero-thermal-elastic effects of the vertical tail become im-

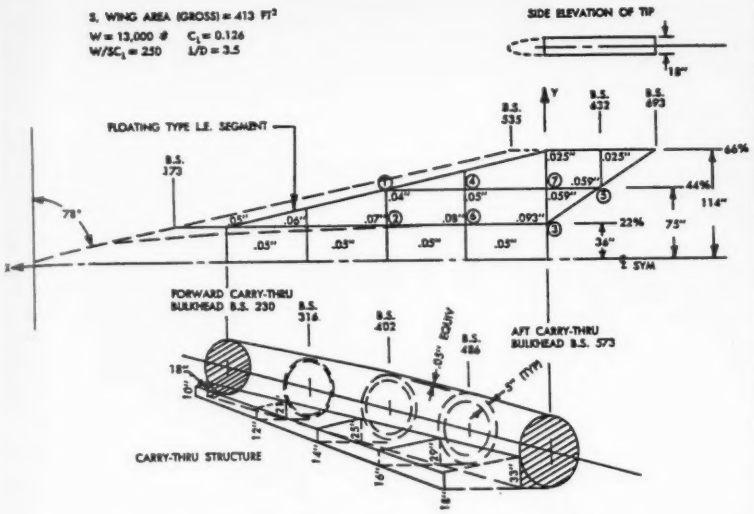


Fig. 3. Low aspect ratio wing configuration. (Material: Inconel 718.)

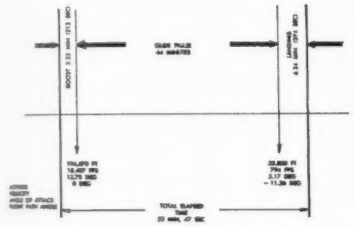


Fig. 4. Time scale of basic trajectory.

portant. If a roll is performed from a steady-state turn, the angle of attack which is consistent with the load factor of the turn also decreases C_{n_β} (Ref. 8). At high Mach numbers, the resulting sideslip causes high vertical fin temperatures which deteriorate the material properties of the vertical fin, cause plastic elongation if the thermal stresses are high, and may cause creep if the time in roll maneuvers is accumulated. These structural effects may become significant if it is necessary to maneuver the glide vehicle every flight at high speed in order to stay within the down-range landing area. After many flights, C_{n_β} may decrease enough so that only marginal rolling velocities can be done without exceeding the directional divergence boundary. As Dryden[9] pointed out, the effect of a rapid heat rise on a surface (this is equivalent to a rapid change in sideslip) is to reduce the torsional resistance of the surface. However, if the roll is done at a slow rate, the resulting sideslip will be less, the

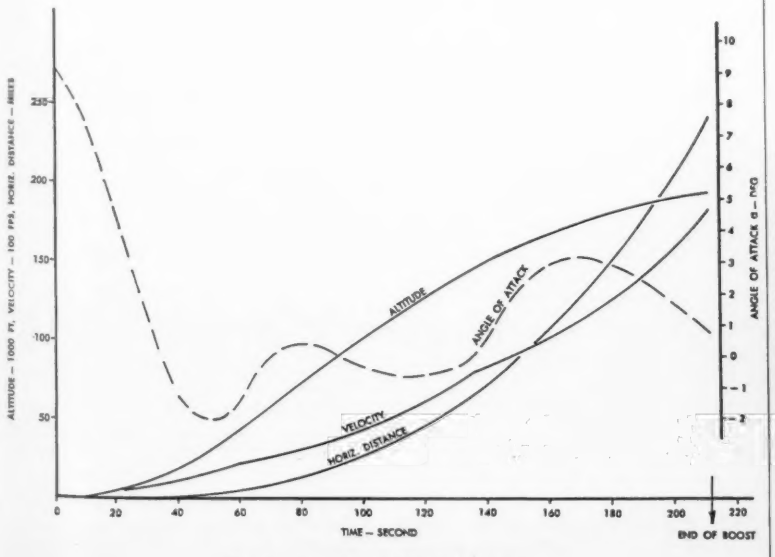
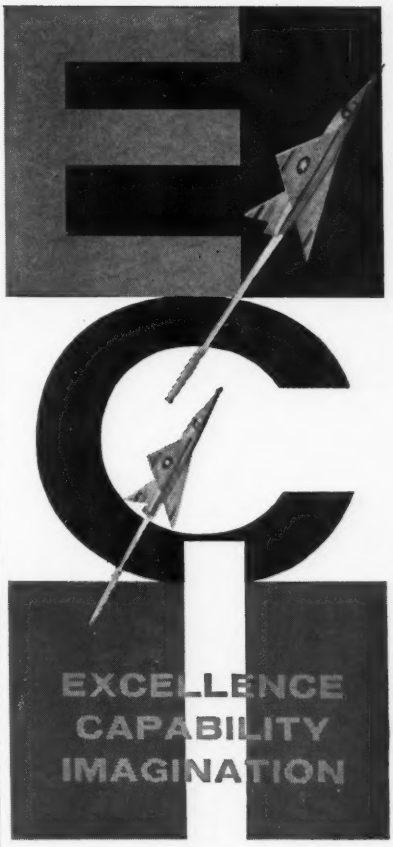


Fig. 5. Boost phase of basic trajectory.



System Development • Communications • Data Link • Countermeasures Actuators • Missile, Weapon and Space Vehicle Research • Infra-Red and Microwave R & D.

ELECTRONIC COMMUNICATIONS, INC.
St. Petersburg, Florida

RESEARCH DIVISION
Timonium (Baltimore), Maryland

ADVANCED TECHNOLOGY CORPORATION (ADTEC)
Santa Barbara, California

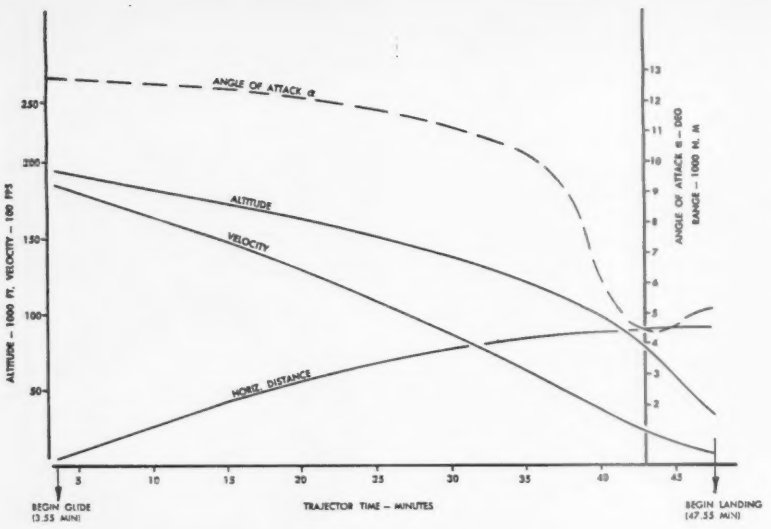


Fig. 6. Glide phase of basic trajectory.

718 looked like a promising material since it was able to sustain the full thermal and load stresses without any permanent set occurring (Fig. 18.)

Repeated exposure effects causing time-accumulated plastic strain may require cold reduction of the Inconel 718 in order to raise the yield strain value at the elastic limit sufficiently to sustain the gradual deterioration on subsequent flights.

Another way to raise the allowable permanent set stress value is to increase the panel buckling values by making sandwich panels. However, as can be seen from Fig. 18, if the panel and structure are effectively restrained by sandwich, the panel stresses increase. If these cover plates are not restrained to the support structure, they will not buckle but cannot be counted on to restrain the structure from its aero-thermal-elastic plastic effects.

vertical surface torsional resistance will be higher and, therefore, the directional divergence boundary will have less likelihood of being exceeded.

Usually, pitch divergence is not a problem on a conventional tail aft configuration inasmuch as the horizontal tail provides a large amount of pitch stability. However, on a swept delta wing, where the stability depends on the lift of the wing being behind the center of gravity, the aero-thermal-elastic effect moves the center of pressure forward as well as inboard. Also, at high angles of attack, the heat on the lower side of the fuselage bends the fuselage nose up which is further destabilizing. These combined effects on C_{m_α}, pitching moment coefficient due to angle of attack, can cause pitch divergence or nonlinear values of C_{m_α} vs. angle of attack. These effects cause pitch up and couple with the destabilizing directional effects mentioned previously to cause either pitch divergence or directional divergence at high roll rates.

The structural mode of failure that seemed to be significant was called the "onset of permanent set." An illustration of this effect is shown in Figs. 17 and 18. At point 2 in the structure (Fig. 3), the cover plates were analyzed using a width of 6 and 8 in. and two different materials, Haynes 25 (L-605) and Inconel 718. The total stress, including temperature and load, is shown as a function of mission time for the normal flight profile σ_{T_2}. The allowable panel compression stress that can be sustained with different amounts of cold reduction was calculated from the following equation[10] and is shown in Figs. 17 and 18, designated $\sigma_{p.s.2}$.

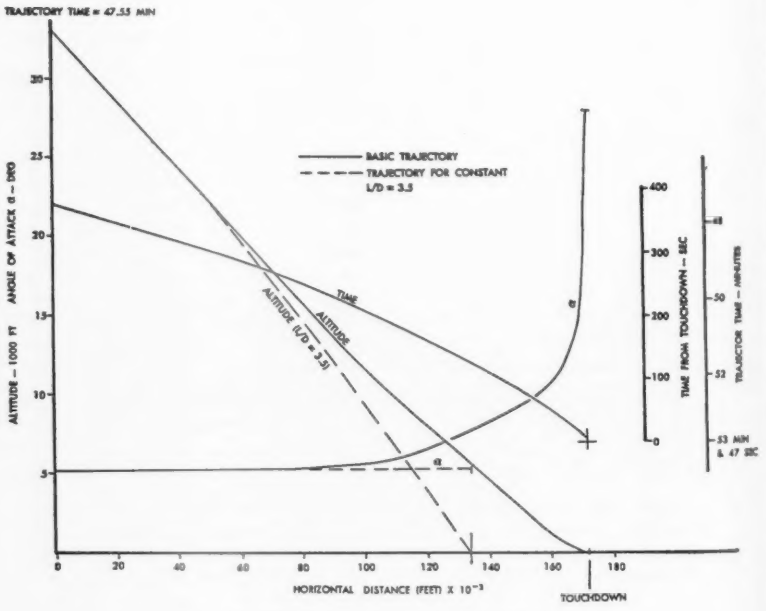


Fig. 7. Landing phase of basic trajectory.

$$\sigma_{p.s.2} = E_s\sqrt{\epsilon_{el}\epsilon_{cr}}$$

where

$\sigma_{p.s.2}$ = stress at which permanent set occurs
E_s = modulus of elasticity of cover skins
ϵ_{el} = strain at elastic limit
ϵ_{cr} = strain at panel buckling stress

For this application, the short-time temperature effects on the material were used throughout the mission. Inconel

Another significant mode of structural failure was the panel compression instability. Using the work developed on pp. 153–155 of Ref. 1, Figs. 19 through 23 were constructed. The panel loading parameter $q/_{L_0}$ is the compression panel stress from load and temperature divided by the effective column length. Bulkhead spacing can be picked by choosing the point where the allowable compression stresses drop significantly from the flat portion of the curve. It is interesting to note that, if

LATEST WORD FROM MARS is the superb new Technico lead holder—with clear-view degree indicator placed right at your fingertips. Contoured for perfect balance, with new positive finger grip, it's the newest of many fine MARS drafting aids—all designed to make your work easier, and to make it look better and reproduce better.

Among the famous imported Mars drafting products are: the Mars-Technico push-button lead holders (with adjustable degree indicator*, with specific degree imprint, the economy model*); Mars-Lumograph drawing leads*, 18 degrees, EXB to 9H; Mars-Lumograph drawing pencils, 19 degrees, EXEXB to 9H; Mars-Duralar pencils and leads for drafting on Mylar®-base drafting film —5 special degrees, K1 to K5; Mars-Duralar Technicos with adjustable Duralar degree indicator; Mars-Lumochrom colored drawing pencils, 24 shades. Also: Mars Pocket-Technico for field use; Mars pencil and lead sharpeners; Mars Non-Print pencils and leads; Mars-Duralar erasers. Mars products are available at better engineering and drafting material suppliers everywhere.

®T.M. for duPONT's Polyester film. *Shown.

the pencil that's as good as it looks **MARS**

J.S. STAEDTLER, INC.
HACKENSACK, NEW JERSEY

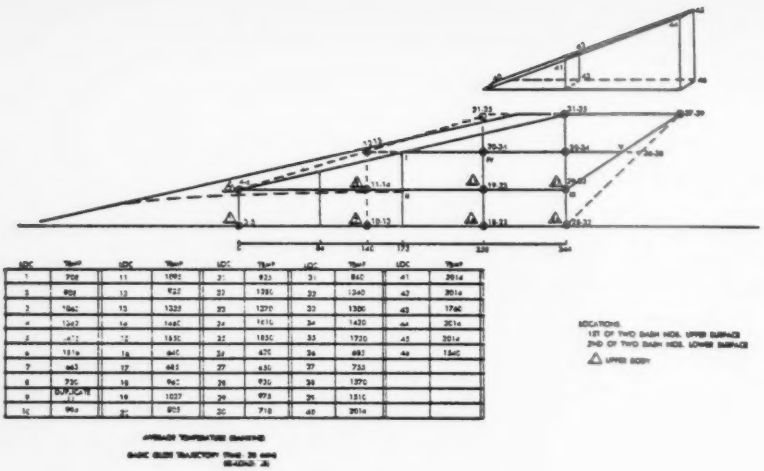


Fig. 8. Glide vehicle, temperature distribution.

full advantage of the cold working is desired, a closer bulkhead spacing is necessary to obtain a higher panel-loading parameter (Fig. 21).

The aero-thermal-elastic effects might also dictate closer bulkhead spacing in order to minimize the chordwise deflections caused by the curling up of the leading edge from thermal stresses. Figs. 22 and 23 have been added to show the comparison of panel weight as a function of temperature and loading using the panel compression stability criteria as a mode of failure. The rapid change in weight near the aging temperature suggested that a "critical" temperature exists for the materials selected. Figs. 24 and 25 accentuate the "critical" temperature. Soaking at higher than the "critical" temperature for any significant time period destroys the "cold work" gain. Therefore, a careful analysis is needed to decide what temperature should be used to age the material. Further discussion of this point is in Ref. 1. The structural stability of a beam column is further complicated by the difference in pressure of the inside and outside of the panel, the difference in temperature of the panel causing thermal moments and the eccentricity of the compression loading and support members. The aforementioned figures did not include the additional effects.

Figs. 26 and 27 show the results of the

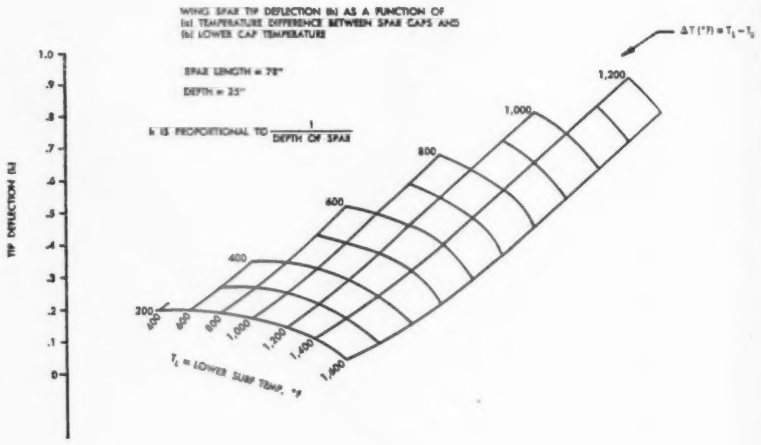


Fig. 9.

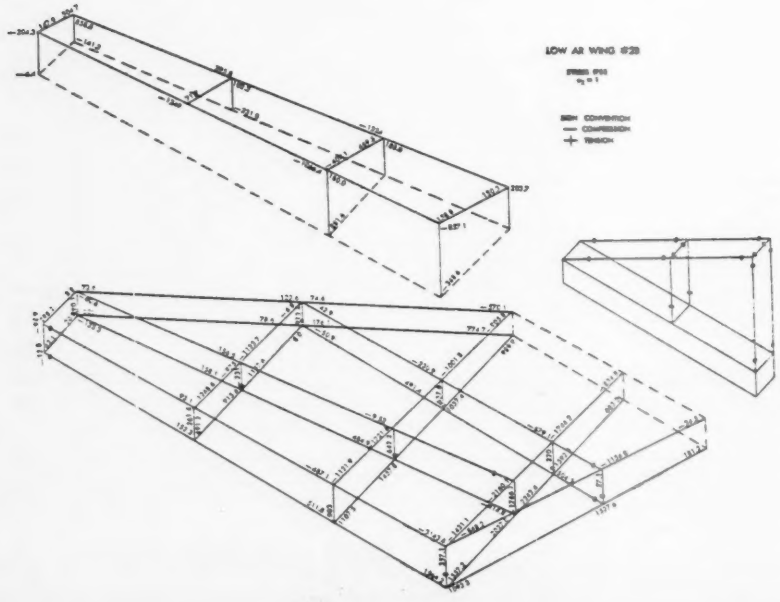


Fig. 10.

structural mode of failure called "panel central deflection." Using the method used in Ref. 11, the temperature on a panel was assumed parabolic due to the heat sink of the end members. The inner and outer skin had the temperatures shown on Fig. 26 which cause thermal moments, and the pressure difference across the panel causes membrane stresses. Finally, Fig. 27 shows the panel central deflection. Even if the panel deflection will not result in permanent set, the magnitude of the central panel deflection may be too large for aerodynamic drag. Also, a large central panel deflection can "trip" supersonic panel flutter and cause control surface "searching" due to the flow changes over the control surfaces. Corrugated panels or sandwich panels can minimize this problem; however, if the panels are made much larger in area when stiffening is used, the thermal differences on the inner and outer sides

SPECIAL ANNOUNCEMENT

IAS NEWS to carry limited personnel advertising

Several IAS Corporate Member Companies have indicated an interest in the possible use of *IAS News* as a medium for recruitment advertising.

They realize, of course, that the 16,000 readers of this monthly bulletin constitute the cream of the scientific, engineering and management talent in all aspects of the aerospace industry today. Many advantages could accrue to both our individual members and corporate member companies if information on certain "personnel opportunities" were contained within these pages and directed to this exclusive audience.

The IAS Publications Policy Committee and Council have approved the acceptance of a "limited amount of appropriate personnel advertising" for *IAS News*, immediately.

Watch for these ads in future issues!

(If you think your own Personnel Manager might be interested in this announcement, why not call it to his attention.)

For details of rates and mechanical requirements, contact representative nearest your area. Listing appears on Page 5.

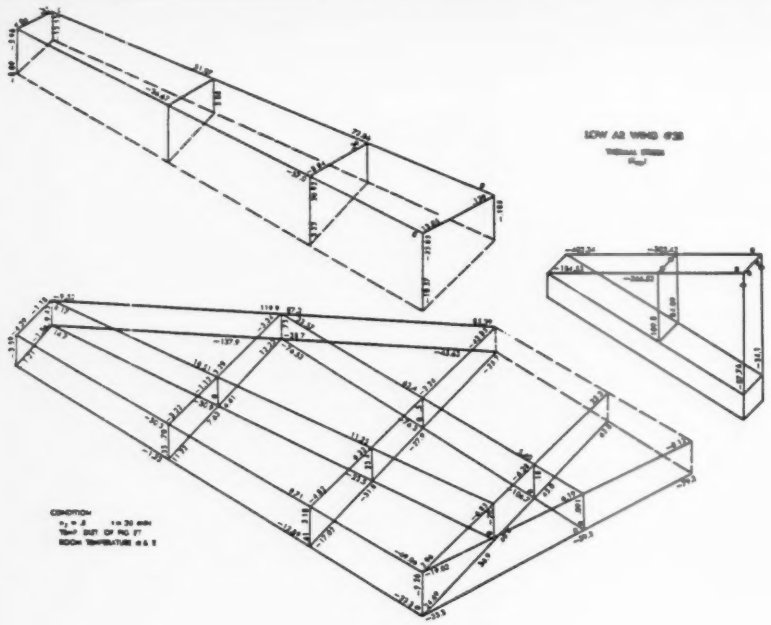


Fig. 11.

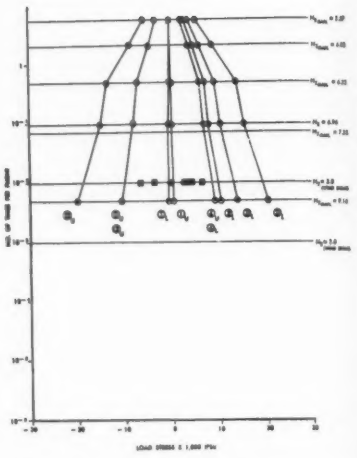


Fig. 13. Planned maneuver perturbation study. (Load stress probability at five upper and lower wing locations during the last 18.8 min of flight.)

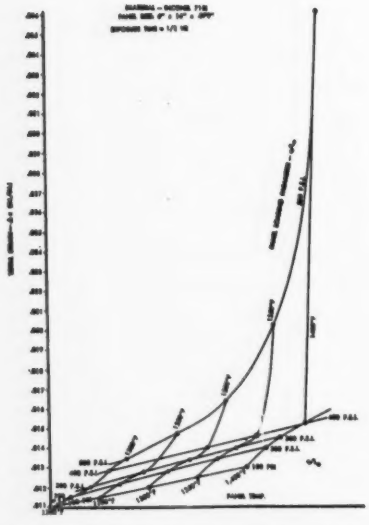


Fig. 12. Compression panel weight and total strain as a function of loading.

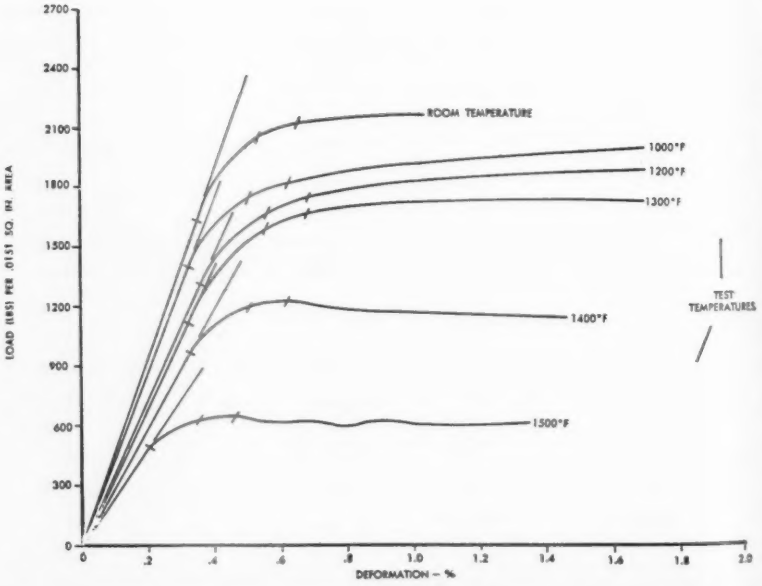


Fig. 14. Load-deformation curves at different temperatures for Inconel 718 aged at 1,300–1,320°F for 16 hours.

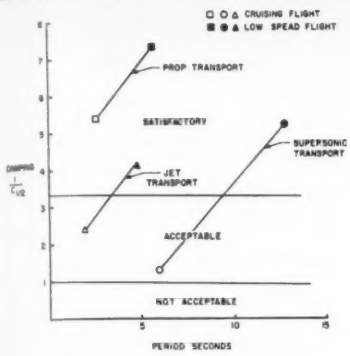


Fig. 15. Dynamic longitudinal stability.

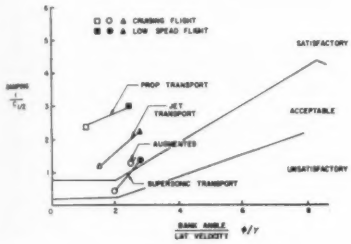


Fig. 16. Dynamic longitudinal stability.

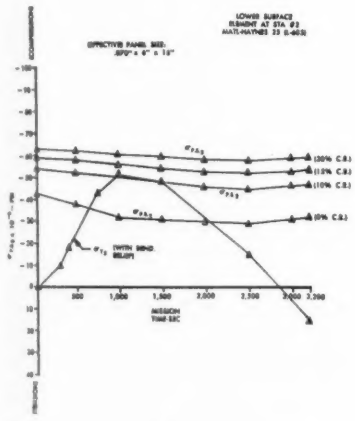


Fig. 17. $\sigma_{p.s.s}$ vs. mission time for various percentages of cold reduction.

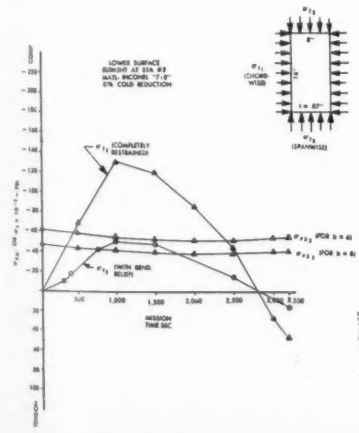


Fig. 18. σ_T and $\sigma_{p.s.}$ vs. mission time.

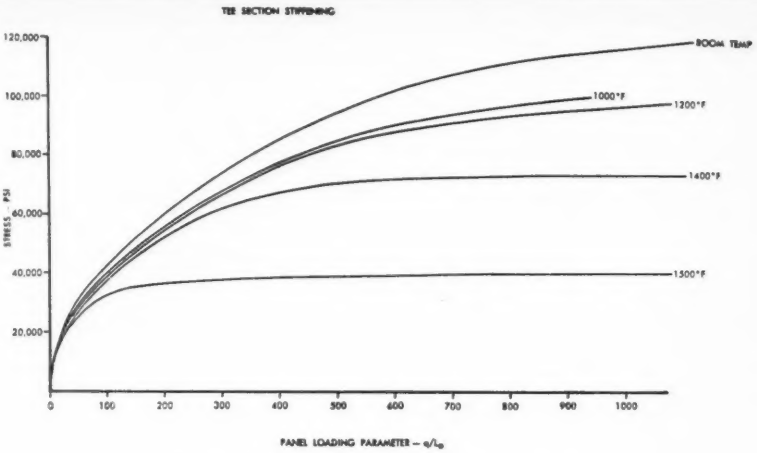


Fig. 19. Inconel 718 optimum compression panel data.

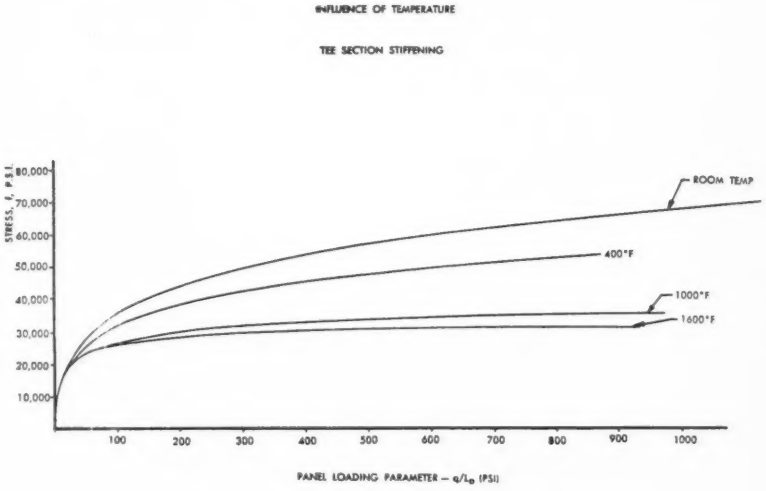


Fig. 20. Optimum panel design allowables—H-25.

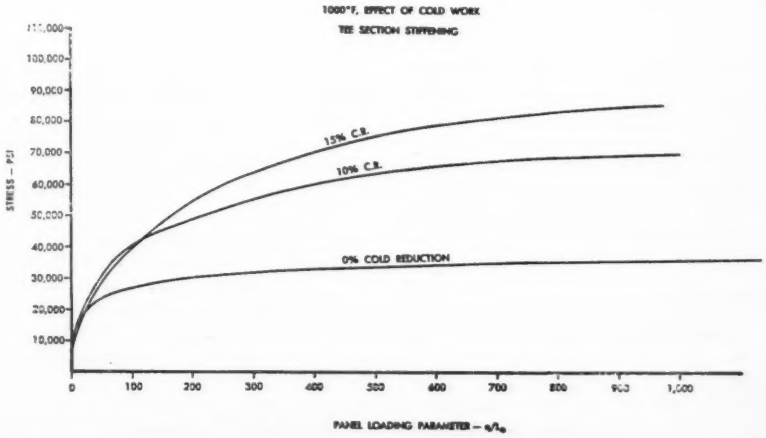


Fig. 21. Optimum panel design allowables—H-25.

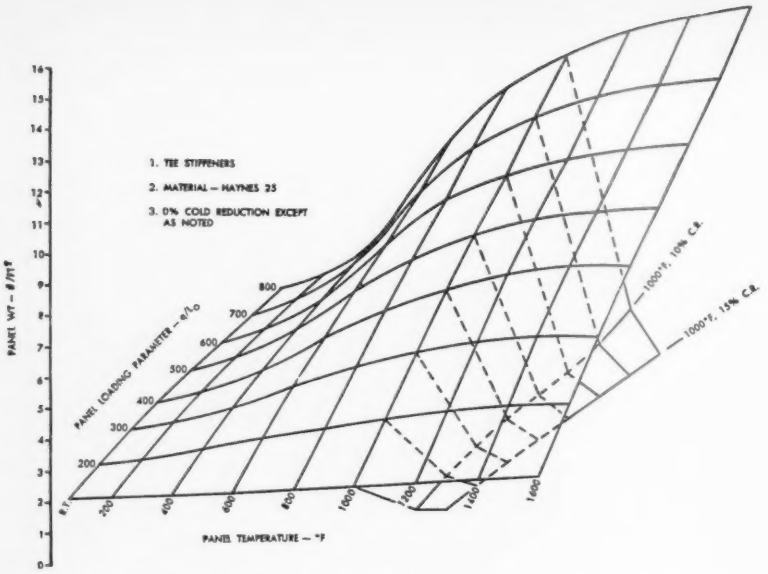

1. TEE STIFFENERS
2. MATERIAL – HAYNES 25
3. 0% COLD REDUCTION EXCEPT AS NOTED
PANEL WT – #/ft²
PANEL LOADING PARAMETER – q/l₀
PANEL TEMPERATURE – °F
1000°F, 10% C.R.
1000°F, 15% C.R.

Fig. 22. Compression panel weight as a function of temperature and loading.

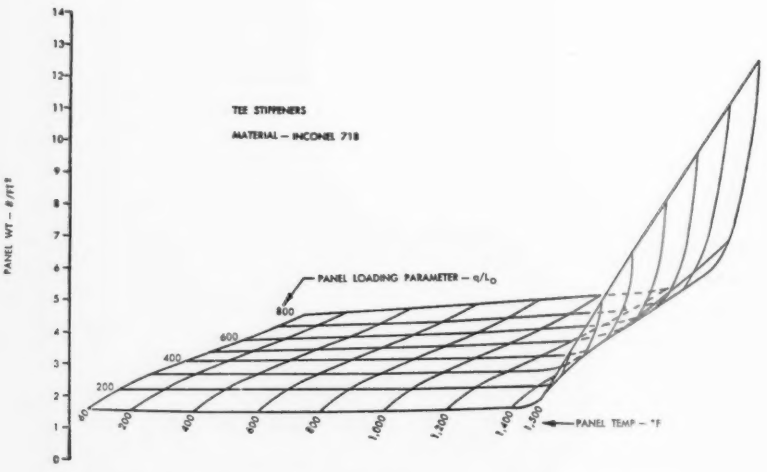


Fig. 23. Compression panel weight as a function of temperature and loading.

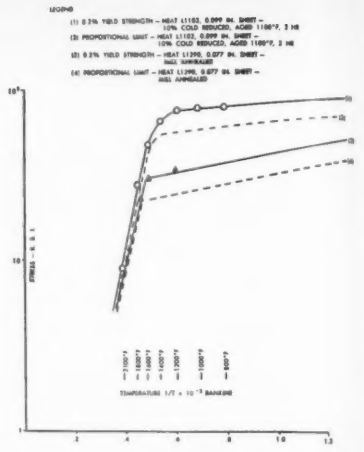


Fig. 24. Effect of temperature on yield strength and proportional limit of Haynes alloy No. 25 sheets tested by Marquardt at 0.001 in./in./sec strain rate.

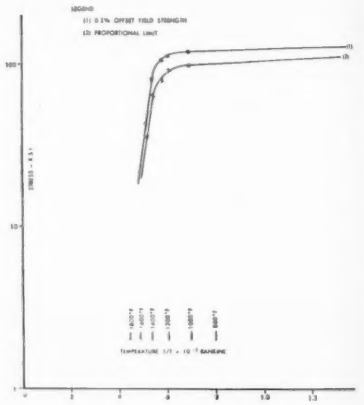


Fig. 25. Effect of temperature on 0.2 percent offset yield strength and proportional limit of Inconel 718 (melt Y8840) sheet, aged at 1,300–1,320°F for 16 hours and tested at 0.1 in./in./min strain rate.

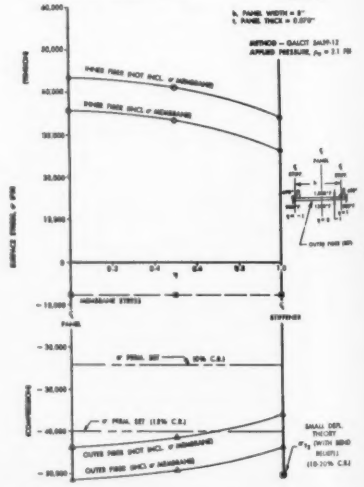


Fig. 26. Wing lower surface element #2 at mission time, 1,000 sec.

of the panel and the heat sinks of larger end member may cause the central panel deflection to become critical again.

In conclusion, a study of the various modes of failure indicate a strong coupling between the aerodynamic, dynamic and structural considerations for a hypersonic re-entry glide vehicle.

References

[1] Davis, J. E., Fischler, J. E., Lobbett, J. W., Saltman, D., Stanwood, J. W., and Tiner, N. A., *Investigation into "More Complete Use of Structural Materials" Through a Study of the Stress-Temperature-Time Conditions of a Re-Entry Vehicle*, WADD TR 60-363, May 1960.

[2] Fischler, J. E., *Modes of Failure of a Hypersonic Re-Entry Glide Vehicle*, Douglas Engineering Paper No. 1035, July 1960.

[3] Fischler, J. E., *Methods for Rocket Boosted Aircraft and Missiles*, Douglas Engineering Paper No. 781, April 1959.

[4] Fischler, J. E., and Lobbett, J. W., *The Influence of Some Non-Linear Aeroelastic Effects on the Correlation Between Theory and Flight Test*, Douglas Report No. LB-25643, Nov. 1957.

[5] Fischler, J. E., Cole, R. W., Clawson, C. N., and Warren, D. S., *Load Methods for High Speed Aircraft*, Douglas Report No. LB-20566, June 1956.

[6] Whitten, J. B., Harper, C. W., and Bellman, D. R., *Supersonic Transport Piloting and Operational Problems*, NASA

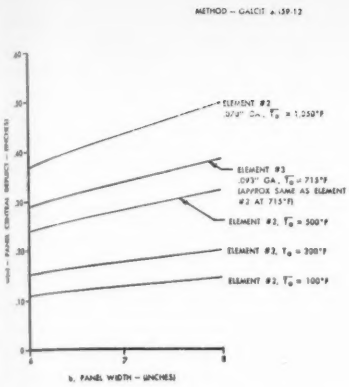

METHOD – GALCIT 4-59-12
ELEMENT #2
ELEMENT #3
.093" GA., T_0 = 715°F
(APPROX SAME AS ELEMENT #2 AT 715°F)
ELEMENT #2, T_0 = 500°F
ELEMENT #2, T_0 = 300°F
ELEMENT #2, T_0 = 100°F
b, PANEL WIDTH – (INCHES)

Fig. 27. Panel central deflection vs. panel width.

Langley Research Center Report given at IATA 14th Technical Conf., Montreal, Que., Canada, April 1961.

[7] Weil, J., and Day, R. E., *An Analog Study of the Relative Importance of Various Factors Affecting Roll Coupling*, NACA RM H56A06, High-Speed Flight Sta., Edwards, Calif., April 1956.

[8] Goodman, A., and Thomas, D. F., Jr., *Effects of Wing Position and Fuselage Side on the Low-Speed Static and Rolling Stability Characteristics of a Delta-Wing Model*, NACA TR1224, 1955.

[9] Dryden, H. L., and Duberg, J. E., *Aeroelastic Effects of Aerodynamic Heating*, presented to AGARD 5th General Assembly, Ottawa, Ont., Canada.

[10] Zender, G. W., and Pride, R. A., *The Combination of Thermal and Load Stresses for the Onset of Permanent Buckling in Plates*, NACA Conf. on Aircraft Loads, Structures, and Flutter, 1957.

[11] Lindquist, D. M. W., *Large Deflection Analysis for a Plate Report Strip Under Combined Pressure and Spanwise Varying Temperature*, GALCIT Report SM59-12, Southern California Cooperative Wind Tunnel Report No. 9-20, June 1959.

✦ ✦ ✦

IAS NEWS

Published on the 15th of the month preceding month of issue by the Institute of the Aerospace Sciences as one of the benefits of Individual and Corporate Membership.

EDITOR:
Allan Bernhardt

EDITORIAL ASSISTANT:
Kathryn Briwa

Effects of Mission on Roll Requirements

(*Continued from page 17*)

lack of damping results in an adverse pilot opinion. The mathematical pilot results, which may be thought of as depicting a human pilot functioning as he would prefer, show a large increase in rms bank angle for an increase in roll time constant. In this case, additional damping is obviously needed.

At present, no specific roll damping requirement is included in the specifications. The most direct approach to a requirement would be specification of a limit on rms bank angle excursion. An attempt at relating rms bank angle to aircraft and gust parameters proved unsuccessful, however, owing to the shortcoming of the overly idealized pilot transfer function representation in precisely the area of interest—low roll damping.

Perhaps the best that can be done on this for the present is a separate specification of minimum acceptable roll damping. A suitable form for a roll damping requirement is not obvious. Although damping should be somehow "equivalent" to that of a one-degree-of-freedom system having a specified maximum time constant, the importance of nonlinearities, notably damper authority limit, makes "equivalency" ambiguous. It would seem that, based on results in references 1 and 6, a roll time constant less than about 1.0 would be desirable; however, the matter appears to be worth further study.

Discrete Gusts

Discrete gusts were studied in the second part of the gust investigation with the same one-degree-of-freedom analog setup and a human pilot "flying" a fixed simulator with a scope displaying the horizon. The gust disturbance followed a 1/2(1-cos) variation and was introduced at the discretion of the machine operator without warning to the pilot. All runs were made using a pilot with about 300 hours B-47 experience.

Only side gusts were considered. Period of the gust and amplitude expressed as angular acceleration due to a gust disturbance were varied, as were the control power and damping-in-roll of the aircraft. It was felt that the average peak bank angle was the best measure of the pilot's ability to control the aircraft. Typical results are pre-

AERODYNAMICISTS

National Research Council
National Aeronautical Establishment
Ottawa, Canada

The National Aeronautical Establishment of the National Research Council, Ottawa, requires a number of theoretical and experimental aerodynamicists to support expanding research programs in its new supersonic and hypersonic wind tunnels, and in modernized low speed wind tunnels.

Preference will be given to candidates with significant experience in appropriate fields, for example: VTOL/STOL, supersonic boundary layers, unsteady aerodynamics, and hypersonics.

Senior, intermediate, and junior positions are available with initial salaries up to $10,000 per annum.

Agreeable working conditions, opportunities for part-time post graduate studies and pleasant living conditions in a residential city with beautiful surroundings.

Applications giving complete details of education and experience should be forwarded to the Employment Officer, National Research Council, Sussex Drive, Ottawa 2, Canada.

In reply please quote NAE-65.

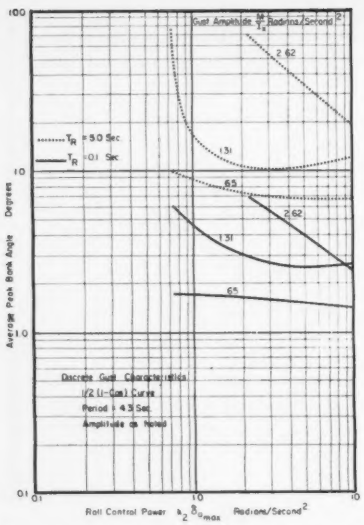


Fig. 4. Average peak bank angle resulting from a discrete side gust.

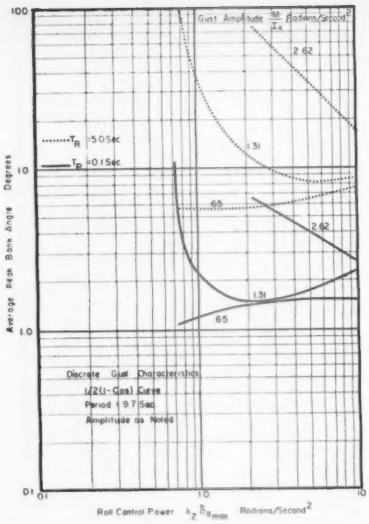


Fig. 5. Average peak bank angle resulting from a discrete side gust.

sented in Figs. 4 and 5. The variation of average peak bank angle with control power is shown for the amplitudes of three gusts in Fig. 4 and repeated in Fig. 5 for a new gust period.

These curves show that, regardless of roll damping available, gust amplitude, or gust period, the peak bank angle increases very rapidly if the available control power falls below the amplitude of the gust rolling moment disturbance.

This rare but critical situation could best be handled in the specification by requiring provision of control rolling moment equal to or greater than the side gust rolling moment for a 50 fps gust. This contemplated requirement offers the designer the option of reducing effective dihedral as an alternative to providing high control power. Such a remedy may indeed be preferable, being directed at the source of trouble. Viewed in this light, the suggested gust requirement appears reasonable.

Maneuverability Considerations

Low-Speed Maneuvering

The primary low-speed maneuver studied was that involved with runway misalignment corrections in landing approach. When landing under GCA conditions, the pilot may break through the overcast only to find that his flight path is misaligned with the runway. This situation was studied by employing a one-degree-of-freedom model and idealized control via optimal step aileron inputs—that is, instantaneous rolling moment. A complete correction sequence involves three bank-and-stop maneuvers—i.e., a bank to a certain g condition, a bank back to the reverse g condition, and finally, a bank back to level flight. The entire study assumed 0.2 Mach number approach speed and a normal load factor no greater than 1.4*g*. Fig. 6 illustrates the flight path of an aircraft performing the three bank-and-stop maneuvers.

Assuming turn load factors from 1.1 to 1.4*g*, and a range of values of control power and damping in roll, the distances traveled down-range while effecting side displacements of 20, 50, and 80 ft were computed. Average roll rate $\phi_{AVER.}$, defined as maximum bank angle divided by the time to reach this angle, has been employed as a parameter.

Results are presented in Fig. 7 in terms of well-defined scatter bands covering variations of load factor, damping-in-roll, and control power. The results indicate a diminishing return in improvement of down-range required to perform the maneuver for increasing average roll rate. In this situation, increasing average roll rate seems to offer very little improvement for values of roll rate greater than about 60 deg/sec.

Two inferences to be drawn from the form of these results are of interest: (1) Bank-and-stabilize capability is the performance measure of interest, and (2) the premium is on down-range distance traversed rather than time.

Since the first statement has also been found applicable to high-speed situations, general comments on this matter seem appropriate at this point. However desirable a bank-and-stop specification may appear, its adoption cannot be recommended because of its unsuitability for flight demonstration purposes. This, of course, is due to the element of pilot skill; a flight measurement of bank-and-stabilize performance would be as much of a test of pilot capability as of aircraft and control system merit. It becomes necessary, therefore, to relate the bank-and-stop performance results of the mission analysis to unchecked maneuver performance.

For aircraft parameter values typical of landing approach (T_R = 1.0 sec, $k_2\delta_a T_R$ = 3.0 rad/sec), the ratio of time-to-bank-and-stop to unchecked-time-to-bank works out to be on the order of 1.3 for 30 deg bank maneuvers. Such a factor must be applied to the average roll rate figures of the mission analysis in order to scale them up to flight demonstration levels for unchecked maneuvers. The idealization of instantaneous (step) control motions has been employed for qualitative analysis purposes. The results so obtained for low damping levels must be interpreted with caution, however, in view of overshoot difficulties impairing performance.

A reasonable requirement for the corrective runway alignment maneuver appears to be about 35 deg/sec on the

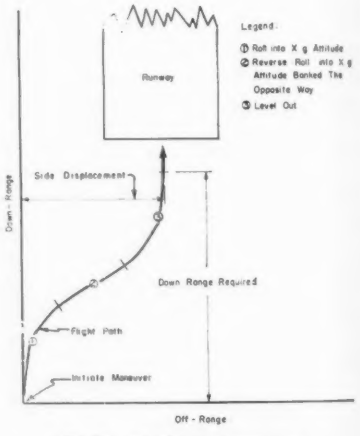


Fig. 6. Misalignment maneuver.

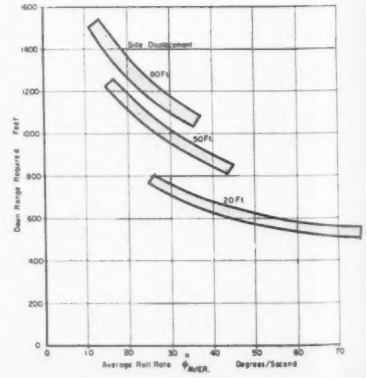


Fig. 7. Effect of average roll rate on ability correct a runway misalignment.

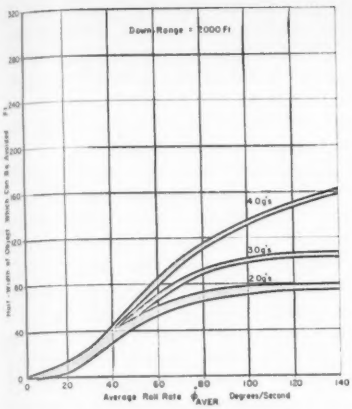


Fig. 8. Effect of average roll rate on terrain-avoidance capabilities.

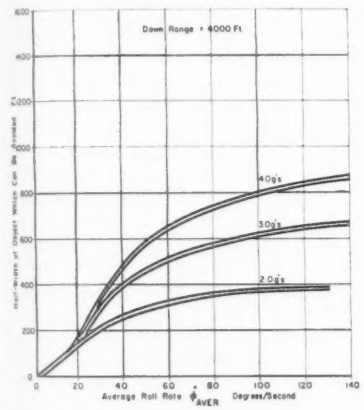


Fig. 9. Effect of average roll rate on terrain-avoidance capabilities.

basis of the results of Fig. 7. This is within 20 percent of the diminishing returns performance level. Thus, at 60 deg/sec average roll rate, down-range required is about 580 ft (the diminishing return level), and at 35 deg/sec, it is 690 ft. The value scales up to 45 deg bank angle in one second for an unchecked roll maneuver. It should be noted that these results are for a single typical landing speed. Since results will undoubtedly be influenced by velocity, some additional work is indicated.

It is suggested that, instead of interpreting this number in terms of the present $\dot{\phi}b/2V$ requirement for gear-and-flaps-down configuration, a requirement of the form $\Delta\phi/\Delta S$, bank angle/distance traveled, be considered. For an approach speed of 224 ft/sec, this points to a requirement of 30 deg of bank in an unchecked roll maneuver in 150 ft down-range distance.

Such a requirement sounds reasonable for all but VTO aircraft. Before a particular figure for performance level is firmed up, however, a check of capabilities of several operational machines against the tentative requirement should be carried out.

High-Speed, Low-Altitude Maneuvering

High-speed, low-altitude maneuvers considered in the mission analysis study were terrain- and collision-avoidance and ground support maneuvers. A terrain-avoidance situation will commonly be encountered during ground support flying. A collision-avoidance situation might be experienced at any time from take-off to landing. The assumed Mach number for the entire study was held at 0.9, however, to be compatible with a ground support mission.

It was assumed that an object to be avoided appears directly in front of the aircraft. The aircraft would immediately begin a roll to a specified g turn. A one-degree-of-freedom roll equation was used and optimal step

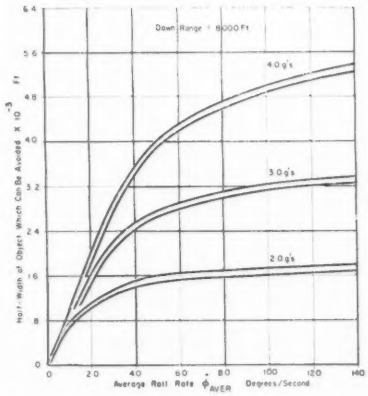


Fig. 10. Effect of average roll rate on terrain-avoidance capabilities.

aileron motions assumed. Aileron was reversed at the proper time to bring the roll rate to zero at the specified bank angle, load factor condition. A constant g turn was continued indefinitely. Both control power and roll time constant were varied over a wide range.

Figs. 8, 9, and 10 plot results for each of three down-range values. The half-width of an object which can be avoided (center of gravity displacement) is presented vs. average roll rate for each assumed load factor. It appears that, for the higher g maneuvers, average roll rate can make an appreciable difference in the size of an object which can be avoided at a given down-range distance. There is a diminishing return effect for increasing values of average roll rate for the low g maneuvers. However, for the situation under study, the higher g results are probably more representative of the maneuver the pilot would elect.

In conclusion, it appears that roll performance is of importance in a terrain-avoidance situation. There is a diminishing return above about 60 to 80 deg/sec average roll rate for a low g maneuver, but appreciable gains can be realized for high g maneuvers through increasing average roll rate over the entire range studied.

The results are equally applicable for a collision-avoidance situation, since here the aircraft must avoid another aircraft which may be thought of as occupying an extrapolated collision position directly in front of it.

In the ground support study it was assumed that the greatest demands on roll performance would result from a misalignment of the support aircraft and the target. Upon detecting a target of opportunity, the support aircraft must roll into a turn and back out of it again, attaining a path leading directly over the target. The support aircraft is ready to launch an attack as soon as he has regained a wings-level attitude. For some target locations, it may be necessary to hold a constant g turn for some period of time prior to rolling out to level flight.

SUPERVISOR—
COMMUNICATIONS

(ELECTRONICS)

Starting Salary to $17,500

If you have a BS EE or Physics and 8–10 years' experience in the design or development of complex, widespread electronic communication systems, perhaps this is the position you have been seeking.

It is a new position; as supervisor of the communications group, you will be responsible for directing and coordinating the work of other engineers to create effective communication systems, including land-line, radio systems at all frequencies, visual systems, countermeasures and such exotic systems as seismic signalling.

Send detailed resume, including salary progression, to

Box 135
Aerospace Engineering
2 E. 64th St., N. Y. 21, N. Y.

An equal opportunity employer.

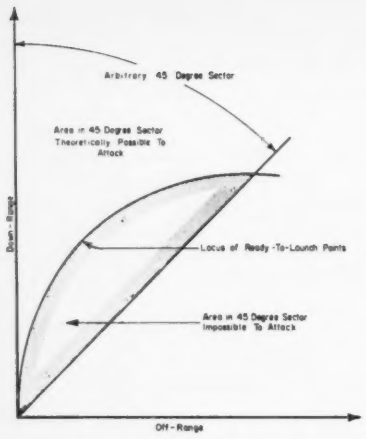

Arbitrary 45 Degree Sector
Area in 45 Degree Sector Theoretically Possible To Attack
Down-Range
Locus of Ready-To-Launch Points
Area in 45 Degree Sector Impossible To Attack
Off-Range

Fig. 11. Coverage of 45-deg sector in ground support study.

In this study the locus of ready-to-launch points was computed over a wide range of airplane control power and damping-in-roll for several values of maximum g. The idealized one-degree-of-freedom roll equation and optimal step aileron motions were again employed.

Under the assumption of coordinated turns, the time history of bank angle allows computation of the off-range and down-range. Although high g maneuvers have been considered, slowdown has been neglected since induced drag at sea level is relatively low, and a high-performance aircraft is presumably in command of considerable excess thrust under these conditions.

The data were reduced in terms of an average roll rate (the ratio of maximum bank angle to the time to reach the maximum bank angle) and a second parameter (Fig. 11) indicative of the success of a maneuver for each locus plot. Here an arbitrary 45-deg sector has beeen defined and the locus of ready launch points drawn. The sector area containing all targets not susceptible to attack was selected as the parameter for rating the maneuver. The smaller the inaccessible area, the more successful the maneuver.

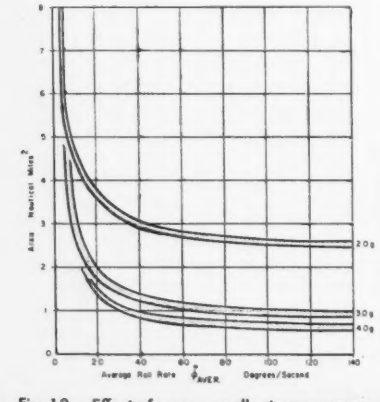


Fig. 12. Effect of average roll rate on area containing ground targets not susceptible to attack.

Final results are plottted in Fig. 12. All of the curves show a diminishing return for increasing average roll rate. Thus, average roll rates higher than about 40 deg/sec do very little to improve the maneuver, while average roll rates lower than 20 deg/sec result in a sharp degradation of performance. It should be noted that these conclusions are not strongly dependent on load factor, although the actual area not susceptible to attack is dependent on load factor.

The relationship between average roll rate as defined in the two studies above, and bank angle attained in one second in the unchecked maneuver used in reference 3, may again be seen by examining rolling motion in a single-degree-of-freedom.

Fig. 13 presents a comparison in terms of the ratio of the following quantities: $\Delta\phi_g$ = bank angle in one second for an unchecked maneuver, and $\Delta\phi_A$ = bank angle in one second for a bank-and-stop maneuver. The ratio has been evaluated vs. roll time constant, the control power canceling out of the ratio.

For a typical value of damping (T_R = 0.3 sec), the ratio is on the order of 1.2. Thus it appears that the average roll rates of the mission analysis should be multiplied by about 1.2 for purposes of comparison with present specification requirements.

In considering the two maneuvers studied, the terrain- and collision-avoidance study continued to show improved effectiveness with increasing average roll rate up to the highest values of average roll rate explored. The ground support study, on the other hand, exhibited a saturation of maneuver effectiveness for increasing average roll rate. Thus, in ground support flying, one comes within 20 percent of the highest obtainable effectiveness with 50 deg/sec of average roll rate.

Correcting this rate with the factor developed previously, the mission would demand about 60 deg of bank in one second in an unchecked maneuver. This value falls below present requirements of low speeds. However, because of the large demand on roll performance indicated in the terrain- and collision-avoidance study, the present specification for low altitude and high speed seems to offer a reasonable compromise.

High-Speed, High-Altitude Maneuvering

All of the high-speed, high-altitude maneuvers investigated are associated with combat situations. Two detailed studies considered interceptor performance requirements for breakaway and for second attack. Many of the data employed in these studies must be deleted for security reasons; however, we may explain how each study was conducted and present certain results with scales on the figures removed.

Breakaway maneuvers are most critical when the interceptor carries a semiactive weapon with a nuclear warhead and attacks a co-altitude target. Under these conditions, too rapid a breakaway will result in failure to illuminate the target until missile impact, while too slow a breakaway will result in the pilot's receiving a radiation overdose. For this reason, then, breakaway under these conditions was studied most intensively.

The general problem was set up as a three-dimensional space problem involving a target, a missile, and an interceptor. The target was programmed to fly either straight-line flight paths or simple g maneuvers at speeds of Mach

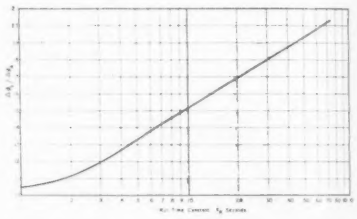


Fig. 13. Ratio of unchecked bank angle to checked bank angle for a one-second maneuver.

2 or 3. The greater portion of the study, however, used straight-line target flight paths and a speed of Mach 3. The missile was programmed to fly a proportional navigation course (navigation ratio = 6, time delay = 0.25 sec, average velocity = 4.5 Mach).

The interceptor launched a missile and began a breakaway maneuver at Mach 3. However, a preprogrammed slowdown was incorporated into the study whenever normal g's exceeded the interceptor's steady-state capability. The amount of slowdown was approximated by solving a one-degree-of-freedom drag equation.

Fig. 14 presents the co-altitude attack results for a target flying straight and level at 70,000 ft and the interceptor performing simple g maneuvers away from the target. An interceptor with a 4g maximum normal acceleration capability can cover about 79 percent of the available launch area utilizing 25 deg/sec average roll rate as compared to 84 percent with instantaneous roll. This can hardly be considered a significant improvement. Several variations of this basic maneuver have been investigated but results are essentially the same.

The same mathematical formulation employed for the breakaway study was used in conjunction with a trajectory study on the drawing board to determine the effect of roll performance on second attack capability. It was assumed that the interceptor launched its first missile at a target at maximum missile range and at various initial look angles. After missile launch, a breakaway maneuver was performed which allowed the interceptor to illuminate the target while remaining outside the radiation boundary. This maneuver was performed according to a composite breakaway doctrine suggested by the preceding analysis.

When minimum range at or after impact is reached by the interceptor, a second attack maneuver is assumed to begin. This maneuver requires the interceptor to roll to a reverse bank and turn back toward the target formation. This part of the maneuver was laid out on a drawing board. In Fig. 15 the entire second attack sequence is shown.

The collision course vector diagram emanating from the "fire second missile" point indicates how the second attack boundaries were developed. At any instant after the second attack maneuver is begun it was assumed that the interceptor is capable of launching a missile at any target with which it is on a pseudocollision course. (A pseudocollision course ignores altitude differential and appears as a collision course between interceptor and target when viewed in a horizontal plane.) The assumption of pseudocollision course launch limits the realism of the results, for if the interceptor were capable of launching a missile against any target within the scan of its radar, the area shown in the second attack zones would be much larger. Selection of a single second attack doctrine does, however, allow the effect of roll performance to be determined.

If we now assume an infinite array of targets all with the same velocity and heading as the first target (a generalized "formation"), all targets on a collision course with the interceptor will be along the "collision course line." The maximum range target will be at maximum missile range, whereas the minimum range target will be at a range dictated by safe breakaway from the second target. This minimum range will be set by the radiation overdose boundary. Thus the area swept out by the heavy lines between these two ranges, while the interceptor performs a second attack maneuver, contains all targets susceptible to second attack within the assumptions of the assumed attack doctrine.

The area containing targets susceptible to second attack is finally plotted in a coordinate system moving with the

Announcing

2 New
ENGINEERING FEATURES
IN *AEROSPACE* ENGINEERING

Written
BY AND FOR ENGINEERS

Our readers will want to watch for these additions to the outstanding technical articles that have made Aerospace Engineering the world's leading magazine for aerospace engineers! See pages 28 and 31!

1. **"AEROSPACE TECHNOLOGY AS SEEN BY THE PANELS":** Up-to-date monthly technical news articles from two or three of the Aerospace Technology Panels to advise the reader on the most important developments that he should know to be current in his specialty. These articles will also provide technical news, more general in nature, giving significances or interpretations of technical breakthroughs or notable occurrences. This feature will be prepared by members of the IAS Aerospace Technology Panels.

2. **"ADVENTURES IN ENGINEERING":** Consisting of a report by the Engineer involved, dealing with a difficult or unusual problem and its solution. The threefold purpose of this new area of Aerospace Engineering is to acquaint Engineers with knotty problems which have been faced on the job by some of their number and how difficulties were resolved, to stress the important role of the Engineer who has applied engineering skill and/or ingenuity in his everyday work, and to provide readers with information which is both illuminating and interesting. Contributions are desired from aerospace engineers everywhere. Authors will be allowed the widest latitude as to style, though use of the first person should be avoided. Manuscripts must be hitherto unpublished, offered to Aerospace Engineering exclusively, and will be subject to confidential review by an editorial board. Excessive use of trade names will be cause for rejection without review. CONTRIBUTIONS MUST NOT EXCEED 750 WORDS. Two copies are desired and should be accompanied by the contributor's (author's) photo (head and shoulders only) and by a 100-word biography prepared in the third person, narrative style.

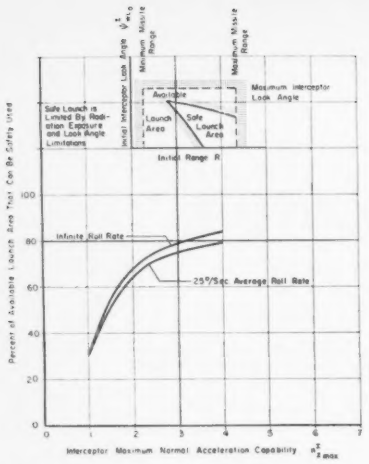

Minimum Missile Range
Maximum Missile Range
Maximum Interceptor Look Angle
Available
Launch Area
Safe Launch Area
Safe Launch is Limited By Radiation Exposure and Look Angle Limitations
Initial Range R
Infinite Roll Rate
25°/Sec Average Roll Rate
Percent of Available Launch Area That Can Be Safely Used
Interceptor Maximum Normal Acceleration Capability

Fig. 14. Effect of roll capability on interceptor's ability to use safely all available launch conditions.

first target. Results for 3g maneuver are presented in Fig. 16. The figure is for initial look angle to first target of 25 deg. The maneuver was assumed terminated when the interceptor speed fell below 2.5 Mach number. The effect of roll performance on the interceptor's second attack capability is not large. However, some increase in targets that are susceptible to second attack may be obtained by higher roll performance. The fact that the situation studied was influenced by three roll maneuvers (roll into first breakaway, roll back to second attack, roll into second breakaway), the last two of which involved banking through angles of 90 to 180 deg, is the reason that roll performance begins to make an impression on the results.

Fig. 15. Second attack sequence.

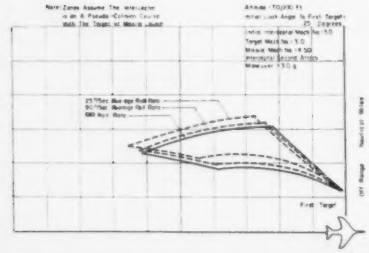


Fig. 16. Zones containing targets vulnerable to second attack.

An obvious shortcoming of the present roll specification as applied to supersonic cruise vehicles is apparent regardless of the preceding results. Fig. 17 presents a sketch of a velocity-altitude diagram with the various zones defined in the specification noted. At present, reference 3 is deficient in the speed range between minimum combat speed and maximum permissible speed at altitudes above 40,000 ft.

This leaves the region where a supersonic cruise vehicle will spend most of its flight time with little specified roll performance. It would seem that the specification could be improved by holding the 20,000 ft lower altitude but stating a flexible upper altitude. This upper altitude should approximate the "service ceiling" and be defined in some similar manner. Such an approach would improve the completeness of the present specification as applied to supersonic cruise vehicles.

With one exception, all of the high-altitude maneuvers studied showed little improvement for bank-and-stop average roll rates higher than 25 deg/sec. In an unchecked maneuver, therefore, $1.2 \times 25 = 30$ deg of bank in one second should be a sufficient requirement. The 1.2 ratio of unchecked bank angle to checked bank angle in one second is for a typical time constant of 0.3. For high altitude this value may be low and, as a consequence, the 30 deg of bank in one second may be low. The second attack maneuvering sequence, employing three bank-and-stop maneuvers, could usefully employ values of average roll rate somewhat higher, but, since no single valid measure of performance could be found for the study, the actual value is not known.

It therefore seems that the high-altitude, high-speed specification requirements should be modified to include altitudes approaching the 1g flight, maximum altitude, but that the level of performance could be decreased over the entire region to 50 deg/sec which is a nominal value between present requirements[3] and those found in the mission analysis.

It may be noted that the results of studies[6] at NASA Ames Research Center indicate a need for a separate damping requirement, and that such a requirement at high altitude appears particularly necessary owing to the adverse low air density effect on natural aerodynamic damping.

Conclusions

The study undertaken has considered both rough air and maneuverability roll requirements and has investigated several specific maneuvers in each category. Results of the study indicate several places where the present roll specification might best be modified.

Out of the continuous gust study, the need for a specific airplane damping requirement became evident. A suitable form for a roll damping requirement is not obvious, however. The matter needs further study before an appropriate form of the damping requirement can be stated.

The study of aircraft encounter with high-intensity discrete gusts shows that this rare but critical situation is more demanding of roll control power than of damping. A tentative recommendation on this is provision of control rolling moment equal to side gust rolling moment for a 50 fps gust.

Out of a low-altitude, low-speed runway misalignment study came two further recommendations for specification change. First, it is suggested that

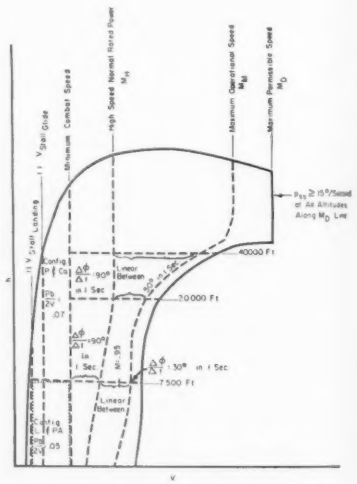


Fig. 17. *V-h* diagram showing present roll specification requirements for Class III aircraft.

replacement of the present $pb/2V$ requirement for gear-and-flaps-down configuration in favor of a requirement of the form $\Delta\phi/\Delta s$, bank angle-distance traveled, be considered. Second, the misalignment study indicates 30 deg of bank in 150 ft of down-range distance is a reasonable requirement for all but VTO aircraft.

Two maneuvers, terrain- and collision-avoidance and ground support, were studied as typical high-speed, low-altitude maneuvers. Terrain- and collision-avoidance maneuvers demanded more roll performance than the present specification, whereas the ground support maneuver demanded somewhat less. It is felt that no change in the specification is required at this time.

In considering the last class of maneuvers—high-speed, high-altitude—only the second attack maneuver

placed any demand on roll performance.

At present an insufficient requirement exists in the specification for altitudes greater than 40,000 ft. It is therefore recommended that the high-altitude, high-speed specification requirements be modified to include altitudes approaching the 1g flight, maximum altitude, but that the level of performance be decreased to 50 deg/sec over the entire region.

References

[1] Aubin, William M., and Kelley, Henry J., *Mission Analysis to Determine Roll Performance Requirements*, WADC Technical Report 59-738, 1959 (Secret).

[2] Aubin, William M., and Kelley, Henry J., *Mission Analysis to Determine Roll Performance Requirements*, Grumman Aircraft Engineering Corp. Research Report RE-125, 1960 (unclassified).

[3] Anon., Military Specification—*Flying Qualities of Piloted Airplanes*, MIL-F-8785(ASG), Amendment 3, Nov. 1957.

[4] Ashkenas, Irving L., and McRuer, Duane T., *The Determination of Lateral Handling Quality Requirements from Airframe Human-Pilot System Studies*, WADC Technical Report 59-135 (ASTIA No. AD 212152), 1959 (unclassified).

[5] McRuer, Duane T., and Krendel, Ezra S., *Dynamic Response of Human Operators*, WADC Technical Report 56-524, 1957 (unclassified).

[6] Creer, Brent Y., Stewart, John D., Merrick, Robert B., and Drinkwater, Fred J., III, *A Pilot Opinion Study of Lateral Control Requirements for Fighter-Type Aircraft*, NASA Memo 1-29-59A, 1959 (unclassified).

✦ ✦ ✦

Missile Range Support of Space Operations

(*Continued from page 19*)

from that point, the only radio transmission was from the payload. As a result, the missile range stations tracked the vehicle within their capabilities but did not create new sites or install new instrumentation to extend their capabilities in support of space vehicles.

Pacific Missile Range—1958

During this three and one-half year period, the Pacific Missile Range was involved in a number of completely different programs. First, they were busily increasing their capabilities at the Sea Test Range for testing higher performance air-to-air missiles fired from supersonic aircraft. Secondly, as a result of the Secretary of Defense directive, they assumed the responsibility for providing range services for IRBM and ICBM training launches of their USAF neighbor to the north at Vandenberg Air Force Base. These services included range safety responsibility, air and sea clearance responsibility, frequency allocation, interference monitoring, and telemetry reception and recording. These functions were not new to PMR personnel because they were previously required for their Sea Test Range operations. Adaptation to ballistic missile operations was necessary. Perhaps the biggest job, in terms of cost, was the impact scoring for these ballistic missiles, which involved underwater acoustic hydrophones in the far reaches of the Pacific.

Tight Schedules

The first Thor was launched from the West Coast one year from the date of the Secretary of Defense directive to Pacific Missile Range. The first Atlas was launched less than two years from this date. PMR was busy enough during this period without the additional problems of space vehicle tracking.

As previously mentioned, Pt. Arguello is ideally located for launching satellites into polar orbit to the south. In a three-year period, there have been 21 Discoverer satellites launched from PMR, the first of which was launched less than ten months after support requirements were provided the Pacific Missile Range.

On the West Coast, as in the case of the Atlantic Missile Range, we again had a situation where the range involved themselves in the launch support problems and did not indulge in satellite tracking, once the satellite was in orbit. For example, Pacific Missile Range ships stationed to the south of Pt. Arguello track Thor and Atlas-boosted satellites to the point of booster burn-out and second stage ignition. However, the subsequent tracking on the first orbital pass is accomplished by USAF project personnel in Kodiak, Alaska. Thus, a pattern was established whereby missile range personnel assumed the role of tracking initially and subsequent orbital tracking was accomplished by project personnel.

The World Picture— The Need for Coordination

If one examines the growth of these ranges and special networks, an obvious question arises:

"Has there been adequate advance planning and coordination?" There never will be "adequate" advance planning if one is a perfectionist and as long as developments in the space business occur as rapidly as they have in the past. From a quick look at the accelerated schedules and deadline dates, it is obvious that time has not been in favor of long-term planning. As to coordination, it is a fair statement that the degree of coordination of the ground support facilities was less than desirable. Parenthetically, however, the accomplishments, in terms of technical achievements and meeting deadlines, were all highly commendable, if not miraculous. However, the administrative mechanism for good coordination did not exist. The Secretary of Defense recognized this situation in May 1960 when he created the Office of Ranges and Space Ground Support under Dr. York, the Director of Defense Research and Engineering. In the past year, this office, under the direction of Lt. Gen. Donald N. Yates, has done much to establish policy to ensure a consistent approach by the three Services. In addition, there has been established well-recognized channels of communication between NASA and DOD at all levels. Within the Space Flight Ground Environment Panel of the Astronautics and Aeronautics Coordinating Board, the policy issues are being actively discussed.

Range Instrumentation vs. G.S.E.

One of the first acts of General Yates' office in mid-1960 was to distinguish between range instrumentation and ground support equipment. Stated briefly, the category range instrumentation (provided by range operators) covers those facilities necessary to track the vehicle through its powered flight up to and including the point of the insertion of a satellite into orbit or insertion of a space probe beyond escape velocity. In other words, once the vehicle is up to stay, the range instrumentation ceases to track the vehicle and the range instrumentation becomes available to be scheduled against the next test. At this point, special purpose ground support equipment (GSE provided and operated by project personnel as opposed to range operators) continues to track for the useful life of the vehicle. This distinction is fairly

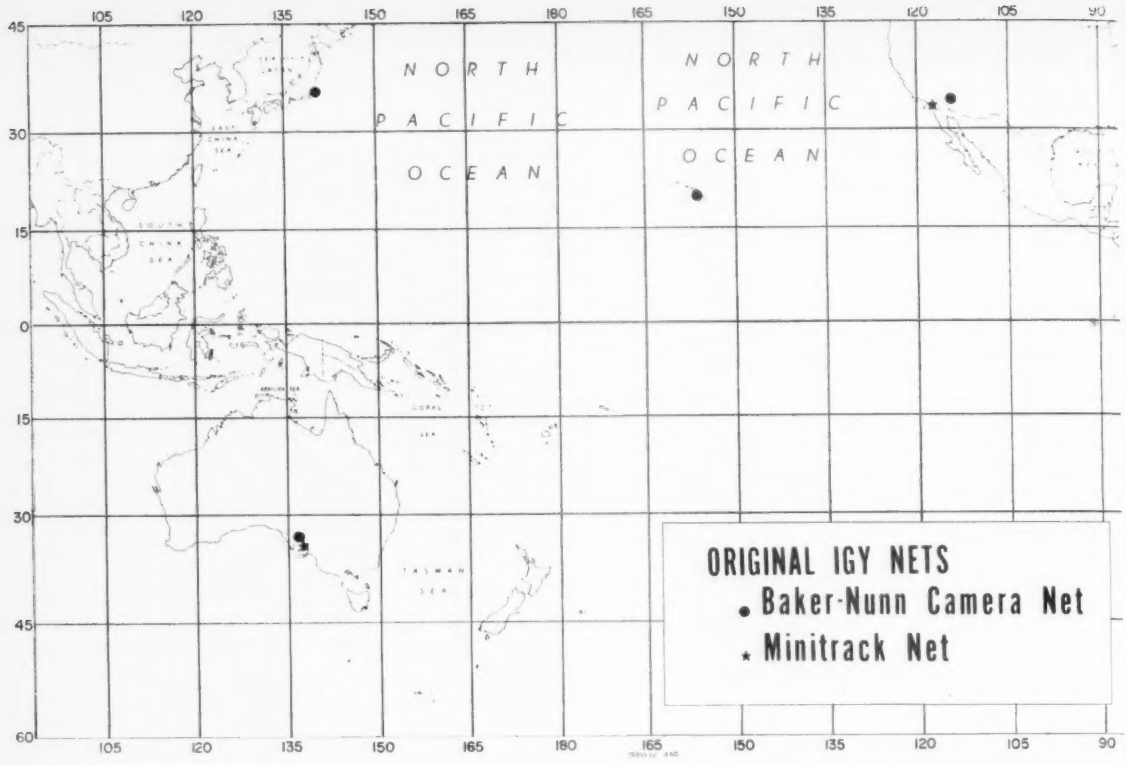

NORTH PACIFIC OCEAN
NORTH PACIFIC OCEAN
ORIGINAL IGY NETS
Baker-Nunn Camera Net
Minitrack Net

Fig. 1.

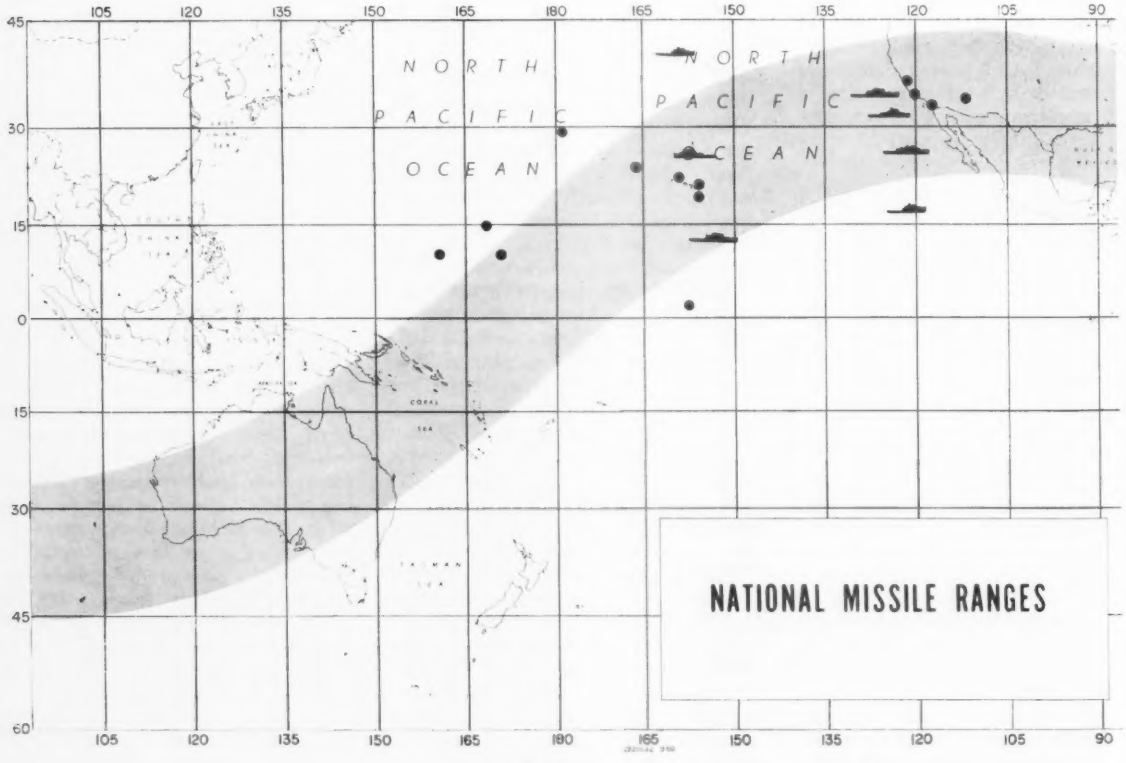

NORTH PACIFIC OCEAN
NORTH PACIFIC OCEAN
NATIONAL MISSILE RANGES

Fig. 2.

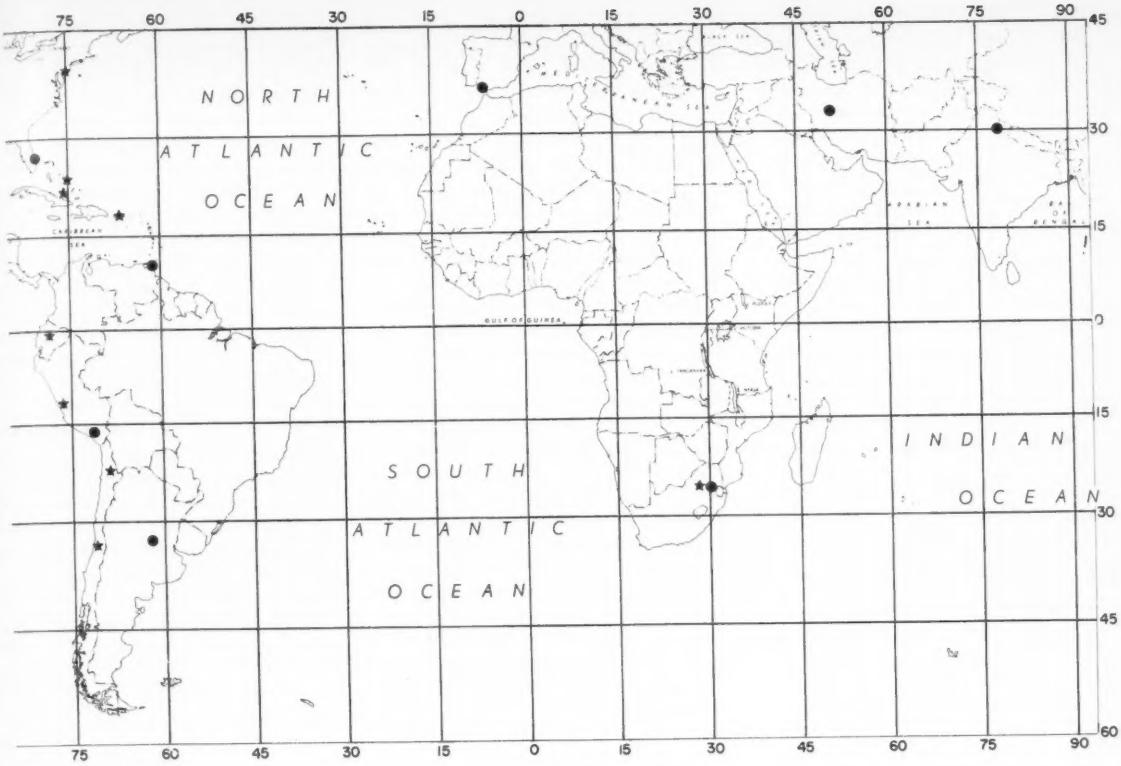


Fig. 1. Original IGY nets.

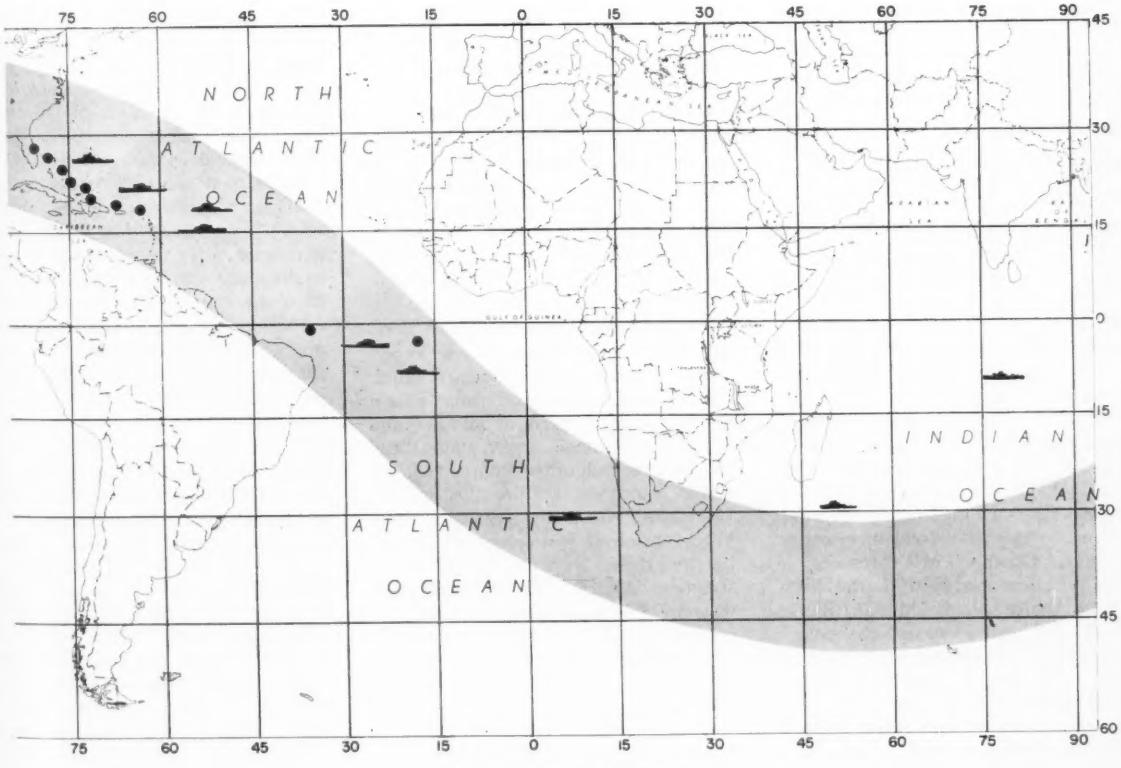


Fig. 2. National missile ranges.

straight-forward and is quite logical for several reasons. First, there would be gross duplication if each of the project teams (and there are dozens of them) undertook to provide instrumentation and tracking during the launch phase. Second, the range instrumentation is fairly versatile in nature, some of it extremely expensive and covering standard functions such as space-position and velocity measurements, as well as telemetry. Third, the instrumentation is used only for the relatively short period of time of powered flight and it then is available for the next scheduled test. On the other hand, the instrumentation required to track the vehicle, once it is in orbit or successfully in outer space, is often uniquely designed to be compatible with on-board receivers and transmitters and conceivably must be available on a 24-hour basis over a relatively long period (the useful life of the vehicle). Thus it is not available, as general purpose range equipment would be, to be applied to the next scheduled test.

There is always the argument that project integrity or project control of the ground instrumentation is necessary. It is agreed that command transmissions or analysis of real time data should be done by project personnel but it is not agreed that other functions of data collection cannot be accomplished adequately by range personnel. In the case of a military project where military decisions must be made as the result of real time data analysis, there is no question that this type of control by project personnel is essential.

National Missile Ranges Encompass the World

Having accepted the principle of range instrumentation operated by range operators, and single purpose GSE by project personnel, it is only natural to inquire into the extent of range capabilities on a global basis.

If one examines a chart of the world, he will find that AMR stations extend down to Ascension Island and, by using ships, the effective reach of AMR is extended well past the Cape of Good Hope. AMR has been assigned the responsibility of range instrumentation covered to the 90° Meridian bisecting the Indian Ocean. PMR is responsible from that line eastward to the West Coast. White Sands Missile Range fills the continental gap in global coverage (Fig. 2). Although the bulk of their assets are concentrated at the launch points, these ranges are now valued in excess of one billion dollars. They have between them instrumentation at 18 different down-range stations plus a combined fleet of 17 tracking ships in their current inventory. In addition, AMR is now acquiring two heavily instrumented ships to extend their capabilities in the South Atlantic. It is quite obvious that these existing national assets form a framework around which our global tracking should be configured.

The obvious question arises as to how one would track a satellite which involves an extended burning time or a series of engine starts and stops which accelerate the vehicle as it circles the earth during powered flight. It is only natural to tie the National Ranges together organizationally, or at least net them for specific operations. Organizationally, they are separately managed by the Army, Navy, and Air Force. Operationally, they are expected to work together in unison to form a global network for tracking. For a leader, they look to the launch range to take the initiative in global planning and supervising the range operation, because the launch range is always the focus of range user activity. The tracking requirements are always the greatest in the launch and boost phase of the operation.

Interrange Compatibility

In order to tie the stations of the three National Ranges together operationally, it is obvious that a high degree of compatibility is required. For the past year, the ranges have been working toward achieving compatibility in their interrange long-haul communications. Through the Interrange Instrumentation Group, an agreement has been reached on a standard timing code format that is to be adopted in all cases involving more than one range. Work is proceeding toward a compatible data transmission system and in radar beacon development. Not only is technical compatibility a necessity, but our operational procedures must be compatible. For example, range superintendents must adopt standard definitions of terms. One range must pass a vehicle being tracked to another and the second range must understand look-angles and other information received and then acquire the vehicle. Underlying this, and perhaps most important of all, is a recent acceptance by the three National Ranges of a standard system of documentation whereby the range user states his requirements and the range evolves an instrumentation solution that is eventually implemented through operational directives.

No discussion of global tracking is complete without mentioning the facilities for NASA's Project Mercury. The astronaut launched from Cape Canaveral will follow a trajectory well chosen to make use of the Atlantic Missile Range Caribbean sites for launch as well as recovery after the third orbit or after the first or second orbit, if return to earth is necessary due to some difficulty. Voice and telemetry communications are required approximately 5 minutes out of each 15. These requirements dictate the choice of orbits and the location of the 17 tracking stations, of which DOD will operate 9, including 2 AMR ships. NASA created eight new stations around the world, including the Goddard Space Flight Center, in completing the network.

An obvious question arises as to whether a new network must be created to satisfy the requirements of each launch azimuth, resulting in a multitude of networks to cover the world. For example, from Cape Canaveral one can launch from any azimuth between 45° to 110° into the North Atlantic, resulting in inclined orbits ranging from about 55° to a minimum of 28.5° without a maneuver. However, the area of the most complete instrumentation coverage follows a southeasterly path down the Bahama chain and over Ascension Island between the continents of South America and Africa. This is the route of the 10,000-mile ICBM flights. It produces an orbit inclined about 30° with the equator. Unless there are other overriding factors, this is the route to be chosen when booster development, including staging, is the problem and a maximum of instrumentation is required. One might choose other inclinations to serve specific payload missions, but only with proven or developed boosters. In such cases, the heavy application of instrumentation, except near the Cape, is not mandatory. In the case of polar orbits from Pt. Arguello, ships down range from the launch point must suffice for tracking although ships' navigation problems are presented. But, again, the polar orbit is attempted for payload purposes and usually with proven boosters.

In summary, the National Missile Ranges have emerged from their early days of tracking missiles from launch to impact. They have formed a cooperative network that permits tracking space vehicles in a global mode. Through lack of policy or direction from the top levels of government, the early space project teams were forced to provide their own tracking facilities beyond the reaches of missile ranges. The pattern is now clear and well defined, allocating to both the range operators and the range users a logical tracking role in the space era.

✦ ✦ ✦

Weather—Take It or Make It (Continued from page 25)

if he but seek it with all his might.

Historically, it was Charles Dudley Warner, not Mark Twain, who said everyone complained about the weather but nobody did anything about it. Whatever its origin, this quip was meant to be humorous, but when a hurricane comes whirling up our East Coast leaving a billion dollar destruction in its wake, to say nothing of casualties, there is little room for humor.

When protracted droughts abort crops, decimate cattle and wreak great losses upon our agriculture, or when prolonged rains swell our rivers and wash away homes, towns, and the soil vital for our future existence, it is a tragedy.

In 1935, the Midwest was subjected to the longest period of hot, dry summer weather in the memory of man. It saw the dust storms, the "Black Blizzards," and the "Dust Bowl." Later, associated with this, Nebraska suffered unprecedented floods in the Republican River valley area.

Again, in 1936, the Midwest suffered disastrous summer drought, and in the following January and February came the longest period of subzero weather and the greatest snowfall ever experienced east of the Rockies. The March thaw of that year caused disastrous floods in the East and in April tornadoes racked the southeast causing great destruction.

Dr. Gayle Pickwell, who records these facts in his book *Weather*, published in 1938, comments, "One cannot experience or read about such weather without asking himself why?" That was 25 years ago and still there is no answer.

The question is—can we do something about the weather besides complain about it? The answer is yes. This is not the isolated opinion of the author, whose career has been chiefly in aviation, but also the opinion of many scientists.

In 1958, the editor of *Science Newsletter* (November 22, 1958) made a survey of professional meteorologists concerning the feasibility of weather control.

Of those queried, 42 percent believed that within 10 years it will be possible to prevent hail and lightning and to increase or decrease precipitation; 46 percent believed that within a span of 50 years man will learn how to control tornadoes, hurricanes and squall lines; and 30 percent believed that large-scale weather patterns will be brought under control within the next 5 decades.

In 1956, Dr. John Von Newmann, one of the greatest scientific minds of our time, said:

> "Our knowledge of the dynamics and the controlling processes in the atmosphere is rapidly approaching a level that will make it possible, in a few decades, to intervene in atmospheric and climatic matters. It will probably unfold on a scale difficult to imagine at present. There is little doubt one could intervene on any desired scale and ultimately achieve rather fantastic effects."

With intensive work all these time periods can be shortened. The fact is that climates have changed and for that matter are changing. We suspect that atmospheric circulation could be changed by altering the absorption and radiation of parts of the earth's surface and we know that in so doing climate and weather would be changed. We know that we can induce precipitation by seeding clouds with dry ice, silver iodide or carbon black, and that in so doing great quantities of energy from the condensation of water vapor can be liberated. There is reason to believe that we can find triggering mechanisms which could make or dissipate atmospheric disturbances.

Some 15 years ago Irving Langmuir of the General Electric Co. made a series of experiments in New Mexico in which he seeded the atmosphere with silver iodide generators at periodic intervals. He claimed that as a result of such seeding the weather on the East Coast was observably affected. Others claimed that it was not. The controversy which arose was never settled, in spite of the far-reaching implications of such an experiment, nor was there any attempt made to repeat the experiment in order to shed light on the subject.

The question is not "who was right or who was wrong," but rather, "is it possible to produce long-range weather effects in this manner, or for that matter, any other way?" A subject of such vital importance should never have been allowed to rest on uncertainty or on opinion.

Skepticism concerning the possibility of weather control appears to stem to some extent from the inability to visualize some specific attack on the seemingly gigantic problems involved. Our immediate objective should be to organize and support a major effort in atmospheric research. Other more specific objectives will inevitably appear as our knowledge increases.

Research in any field does not require a specific goal to be practical, but merely a direction. As the horizon in any direction is rolled back by new knowledge, concrete possibilities begin to appear which were not visible from the starting point. Unseen discoveries lie beyond every horizon, their existence is certain, their availability depends only on faith and hard work.

The influence of weather control or modification on every phase of human activities beggars the imagination. Only slight improvements in precipitation or temperatures could result in making vast territories available for agriculture and normal living.

Small changes in atmospheric circulation could bring about more favorable temperatures to make additional areas suitable for human habitation. It is conceivable that hurricanes could be diverted or their force dissipated by breaking them into small disturbances before the system could gather all its destructive energy into one great storm. The yearly toll of disaster and enormous losses could be avoided or at least reduced by the capability of controlling or modifying the weather.

From a military standpoint, the implications are even greater. With control of weather the operations and econ-

Table 1. Meteorological Research Appropriations

Agency	Total Budget (millions)	Meteorological Research Support, 1959 (millions)	Percent of Budget
Department of Agriculture	5,926	0.9	0.15
Atomic Energy Commission	2,723	1.3	0.7
Department of Commerce	471	1.6	0.34
Weather Bureau	452	1.8	0.40
Department of Defense	45,517	18.3 (total)	0.028 (total)
Army		2.9	0.007
Navy		3.0	0.007
Air Force		6.8	0.17
Department of Health, Education and Welfare	3,255	0.9	0.27
Department of the Interior	791	0.1	0.013
National Aeronautics and Space Administration	305	8.6	2.8
National Science Foundation	136	8.1	6.0
TOTAL		36.0	

omy of an enemy could be disrupted and, by the same token, we could be made to suffer enormous losses in our own economy and our military effort crippled.

In a cold war, the ability to control or modify weather would provide a powerful and subtle weapon to injure agricultural production, hinder commerce and slow down industries.

How then do we go about harnessing the weather? The answer is first to learn more about our atmosphere and its mechanisms. This calls for research and experiment, not on the present penny-ante style, but on a scale commensurate with the immense benefits to be gained. This, in turn, calls for major expenditures to provide for scientific personnel, equipment and the necessary educational program to create a source of competent workers for this field.

In addition, it requires support for a group of specialists whose primary objective is to apply current knowledge to the control or modification of weather as a point of departure. In spite of the meager support of meteorological research in the past, a good deal of basic work has been done by a relatively few competent and dedicated scientists. This work could begin to show tangible results if expanded and supported by experiment.

The development of mathematical weather models by means of computers and the simulation of circulation by means of water tank analogy has already provided modern tools for weather study. With more aircraft, rockets, balloons, etc., and personnel for observation, we could arrive more rapidly at the point of full-scale experiment. We have recently launched a weather satellite which, along with others, will provide much needed information. (I suspect, however, that this fortunate development was dictated more by our desire to expand our space technology than for the benefit of meteorology!)

We could do some things immediately; for instance, eliminate or greatly reduce air pollution around our cities which dims sunlight, causes poor visibility, promotes fog and increases the collision hazard at our great air terminals. Those of us who fly in and out of New York have seen the pall of smoke which blankets the area for miles on relatively calm southwesterly days. The smog of Los Angeles is largely man made. Why do we deliberately degrade our weather?

As an investment, the reduction in smoke and vapors would save our airlines millions a year by reducing delays, reducing hazards which we cannot price, and certainly by improving everyone's health. It has been estimated that air pollution costs our country over $1 billion a year and untold respiratory troubles.

Some of our cities such as St. Louis and Pittsburgh have already made major improvements. Why not a national effort in this line?

The present scale of appropriations for Meteorological Research is pitifully inadequate for the task at hand, and it falls far short of that needed for current operations for the collection of available new data.

Table 2. Various Disciplines and Graduates Therefrom

Course	Degree B.S.	M.S.	Ph.D.
Physical Sciences	15,460	3,179	1,812
Mathematics	9,019	496	28
Engineering	38,134	6,753	714
Biology	15,149	2,002	1,045
TOTAL	77,762	12,430	3,599
Meteorology	173	88	13

We have not enough aircraft for observation, not enough personnel for the collection and analysis of data and virtually no support for experiment.

The records show that in 1959 the total amount appropriated for Meteorological Research by all departments and agencies was some $36 million. A good part of this was spent on equipment. Despite its importance, only about a million was directed specifically to the field of weather control or modification. The projected sums for 1960 and 1961 are $1.5 million for each year.

Contrast this sum of $36 million with $45 billion for a defense budget; when even minor modification of weather could turn out to be a super weapon to enhance military strength, or an economic bonanza. A mere $36 million effort or for that matter a $50 million effort just does not make sense.

Table 1 shows the budget of the various departments and agencies which support Meteorological Research and the amount of their support in dollars and as a percentage of their respective budgets for the year of 1959.

The meager support devoted to Meteorological Research clearly indicated the low category of importance to which this work is relegated.

Even with the projected research expenditures for 1960 and 1961—$38.5 million and $48.5 million, respectively—this comment remains applicable. The development of the satellite program to provide us much-needed information will add about $50 million to weather projects this year. But this expenditure actually is for equipment rather than research. Even so, there seems to be a shortage of manpower to process intelligently data being obtained from satellites which will require added financial support not yet provided for. With the exception of NASA and NSF, where substantial increases for 1961 are noted, no significant changes have occurred in allocations for Meteorological Research, which appears to remain in a relatively low category of importance.

It should be borne in mind that any increase in knowledge of our atmosphere and its existing movements will permit better forecasting which is badly needed. It should also be borne in mind that even now a great deal needs to be done to make available to those concerned such current weather information and short-term forecast as we now have. This means more and better personnel for the Weather Bureau and better communications. There could be no better national investment.

It has been said that it would not be wise to provide more funds at this time because the number of technically qualified people in the field of meteorology is very limited.

The answer obviously is that so little money has been available for research in meteorology that young technical students seeking a career are not attracted to this field in spite of the challenge it presents. Table 2 shows the number of students graduating in the various technical fields as compared to those graduating in Meteorology for the year 1959.

All told, there were some 77,000 graduated from engineering and other technical courses with only 173 B.S.'s and 13 Ph.D.'s in Meteorology. We cannot expect to improve enrollment unless we show our interest and the vital need for study in this field by providing more funds for research and experiment to prime the educational pump with educational incentives.

Corresponding figures for 1960 are not available as of this date (7/17/61); however, indications are (although the figures are on the upward trend for all disciplines) that no adequate change has occurred insofar as Meteorology is concerned.

The question inevitably comes to mind as to what some of our less friendly contemporaries, such as the Soviets, are doing in this field. Actually, we do not really know but we do know that they have capable scientists, that they have the power to direct their research efforts where their hierarchy sees fit and that they have great advantages of terrain for experiment.

They have the vast reaches of the Siberian continent for experiment and can observe results on possible changes of surface and the effects of seeding clouds and other experiments without hindrance. We know they are working on cloud physics, fog dispersal and other meteorological projects but for the last 4 or 5 years their publications of experiments or results have been meager. Is it because of the lack of work in this

field? It is more likely because this work has been classified and they are keeping the results to themselves.

There are those who contend that we are ahead of the Soviets in meteorology. They could be right, although I doubt it. But so what? It would be a relief for once to lead the field in this vast enterprise to control weather (as we did in the nuclear devices development) using our own initiative and good sense to better our existence and protect ourselves, without requiring the goad of Russian competition to get started.

We must realize that weather control or modification, like nuclear energy, involves world problems. If we change the weather in some parts of the world it will probably affect the weather in other regions. How? Research and experiment will give us the answer which we hope could result in benefits to all mankind. Regardless of these problems the control of global climate and weather will eventually be tackled though it be fraught with danger, both physical and political, in view of the pressure generated by growing population and perhaps, most of all, because man will never stop trying to harness the forces of nature to his use.

Perhaps it is a matter for the United Nations to consider. Such consideration at an early stage might conceivably avoid bitter conflicts or even war later on.

In the foregoing I have tried to bring out the importance of Meteorological Research in comparison with other scientific fields and the disparity in the interest and the research effort it receives. It seems time to establish a sense of proportion between the value of even limited weather control capability and better forecasting and the funds allocated to bring about these results. Certainly the end results, weather control, justify the same consideration as that which was given to nuclear development and it should be treated as such. We have led the world in nuclear power, why not lead the world in meteorology and its application?

As a starting point for a national program the following specific immediate objectives are suggested:

(1) Increase the financial support of basic Meteorological Research from $36 million in 1959 to $100 million a year, starting now and being prepared to increase this as circumstances permit.

(2) Increase the output of Ph.D.'s in Meteorological Research tenfold during the next 2 years. (This could be facilitated by evincing greater interests in Meteorological Research and offering educational incentives.)

(3) Expand research in weather control from a rather restricted field of cloud physics and cloud seeding to include investigation of the dynamics of the atmosphere on a planetary scale from the standpoint of triggering mechanisms. (Scientific means to reach this objective are now at hand in simulation of the atmosphere on electronic computers and hydrodynamical models. Furthermore, much greater consideration must be given to the interaction between the atmosphere and the sea which covers nearly three quarters of the surface of the earth. Authority for such work already exists under Public Law 85-510.)

(4) Accelerate exploitation of the enormous power of meteorological satellites to bring global weather systems under surveillance. (This should not be limited merely to taking photographs of clouds but should include the use of sophisticated sensing devices for the reconstruction of three-dimensional fields of pressure and temperature on a world-wide basis.)

(5) Initiate studies to assess the legal, economic and social implications of large-scale weather modifications.

From the standpoint of importance to our present and future existence, we might well consider the control of modification of weather in the same category of importance as that we attached to the Manhattan Project which yielded the first atomic bomb.

+ + +

IAS/ARS JOINT MEETING

LOS ANGELES, JUNE 13–16, 1961*

IAS/ARS MEMBER PRICE—$0.50 each

NONMEMBER PRICE—$1.00 each

61-88 -1782 Trends in Air Cargo—H. Carter & J. Jackovich
61-89 -1783 Factors Underlying the Future Domestic Market for Air Cargo Service—G. Busch & K. Mayer
61-91 -1785 Air Trailer Transportation—W. Ligon
61-92 -1786 Economics of Air Eligibility—L. Regan & G. Harris
61-95 -1789 Maximizing Reliability for One-Shot Space Missions—S. Morrison
61-96 -1790 One-Shot Mission Success for Minimum Cost—W. Cox & W. Harter
61-104-1798 Short Haul Air Transportation—W. Kennedy
61-105-1799 Aerodynamic Characteristics of Subsonic V/STOL Transport Airplanes—M. Kelly & C. Holzhauser
61-106-1800 Application of Laminar Flow Control to Transport Aircraft—W. Gasich
61-107-1801 Hypersonic Airplane Performance—A. du Pont
61-114-1808 Supercircular Entry and Recovery with Maneuverable Manned Vehicles—R. Smith & J. Menard
61-115-1809 Prediction of Optimum Approach & Landing Techniques-Manned Reentry Gliders—L. Gaines & T. Surber
61-116-1810 Second Order Theory of Entry Mechanics into a Planetary Atmosphere—W. Loh
61-118-1812 Instrument Flight Simulator Study of VTOL Controllability-Control Power Relationship—J. Patierno & J. Isca
61-119-1813 Design Characteristics of a Lifting Fan V/STOL Logistic Transport—E. Kazan & W. Bergen
61-120-1814 Influence of Two-Dimensional Stream Shear on Airfoil Maximum Lift—R. Vidal
61-121-1815 Design of Supersonic V/STOL Fighter-Bomber—J. O'Malley, Jr.
61-123-1817 Age Concept of Management for Ground Environment Area—S. Tremaine
61-124-1818 Universal Program-Comparator Checkout Equipment & Logistical Considerations—E. Metsker & M. Beeson
61-125-1819 Role of Operational Analyses in Planning Effective Missile Ground System—S. Firstman
61-126-1820 Compiling of Automatic Test Equipment Programs—E. Quinn and C. Chipps
61-129-1823 Study of Solid-Fuel Ramjet Applications—P. Munter
61-134-1828 Description of Weapons Assignment Research Model (WARM)—R. Totschek
61-135-1829 General Purpose Simulator for Airborne Computers—E. Carter
61-143-1837 Design Alternatives for In-Flight Maintenance—R. Demaree
61-144-1838 Human Engineering Principles of Design for In-Space Maintenance—L. Pigg
61-145-1839 The Use of Tools in Space–An Empirical Approach—J. Celentano & H. Alexander
61-146-1840 Predicting Human Reliability-Implications for Operations & Maintenance in Space—R. Kaufman, T. Oehrlein and M. Kaufmann
61-147-1841 Some Experiments of Human Maintenance Behavior—M. Grodsky
61-149-1843 Unified Engineering Theory of High Stress Level Fatigue—S. Valluri
61-150-1844 Structural Aspects of Low Drag Suction Airfoils—J. Wieder and W. Pfenninger
61-151-1845 Leading Edge Design with Brittle Materials—F. Anthony and A. Mistretta
61-158-1852 Mercury Animal Program—J. Henry and J. Mosely
61-162-1856 The Mini-Recorder System—J. Renfro
61-183-1877 Directive Non-Oriented Reflectors as Passive Satellites in Long Distance Communications—Y. Stahler and A. Johnson
61-190-1884 The Magnetic Particle Clutch–A Versatile Control Element for Rocket Systems—B. Grau & B. Chubb
61-194-1888 X-15 Flight Simulation Program—N. Cooper
61-195-1889 Piloted Simulation Studies of Re-entry Guidance & Control at Parabolic Velocities—R. Wingrove & R. Coate
61-196-1890 The Simulator as a Human Factors Research Tool for Manned Space Flight—G. Simon
61-208-1902 Flow Field Analysis–Lifting Re-entry Configurations by Method of Characteristics—L. Fowell
61-210-1904 Flow Past Slender Blunt Bodies–Review & Extension—R. Capiaux and L. Karchmar

*See page 63 for other IAS publications available.

Order by number from: Special Publications Dept., IAS, 2 E. 64th St., New York 21, N.Y.

Supersonic Transport Propulsion (Continued from page 13)

tive over a broad range of Mach number. Also, the predicted trend of cruise efficiency of the supersonic machine with Mach number is shown to be relatively flat so that an optimum flight speed cannot be defined on this basis and must be established from other considerations.

The high potential productiveness of the supersonic transport is frequently quoted as one of its major advantages. The gains made possible in this area through substantial increases in block speed are obvious. The situation with regard to the other ingredient of productiveness—amount of payload carried—is much less clear. Indeed, serious problems are encountered.

Typical breakdowns of the take-off gross weight are presented in bargraph form (Fig. 3) for three transports designed for 3,500 nautical-mile ranges: a turboprop, a subsonic jet, and a supersonic jet. The factors considered are engine (or engine plus propeller) weight, fuel weight, structure and miscellaneous weights, and payload. It can be seen that, as one progresses from the turboprop to the subsonic jet and then to the supersonic jet, the percentage of gross weight devoted to engine and fuel increases significantly. As a result, structural problems become more acute, and the amount of payload decreases drastically. The supersonic machine tends to be much bigger than the subsonic machine designed for the same payload, and its economic success depends to a much greater extent on the attainment of the design values of engine weight, fuel consumption, and structural weight. A small slippage in any one of these areas requires large increases in airplane gross weights to maintain a given payload.

Research and development work conducted in connection with the B-70 and other military projects has pointed the way to the attainment of high levels of efficiency in supersonic cruising flight. Unfortunately, the airframe and engine configurations developed in these programs cannot be used directly because the requirements of the civil transport differ greatly from those of the military machine in the areas of operational techniques, safety, public acceptance, and economics. A calculated flight profile for a typical supersonic transport mission will be used as a framework for introducing and explaining these differences.

The mission shown (Fig. 4) is a 3,500-nm New York to Berlin flight with a total trip time of $2^1/_2$ hours. Altitude in thousands of feet is plotted against trip distance in nautical miles, with Mach numbers and elapsed times spotted along the profile. The take-off and subsonic phase of the climb out are similar to that for present jets except that the initial climb angle may be

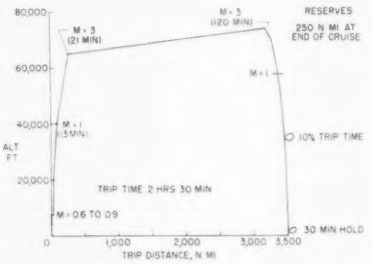


Fig. 4. Typical supersonic transport mission profile.

steeper because of the increased thrust-to-weight ratio. For reasons that will be discussed later, the subsonic climb may have to be maintained to appreciably higher altitudes than the cruise altitude of the subsonic jet. At the peak subsonic altitude, the thrust is increased greatly by afterburning or other means of thrust augmentation and the airplane accelerates through sonic speed and continues to climb and accelerate to its initial cruise condition of, in this case, Mach 3 at 67,000 ft. If the cruise Mach number were 2 instead of 3, the cruise altitude would be approximately 10,000 ft lower. The problem areas pertinent to the engine in this segment of the flight include take-off distance and speed, noise generated during take-off, sonic booms generated during transonic and supersonic operation, and very high fuel consumption.

For the flight profile shown, the airplane cruises at Mach 3 at reduced thrust levels for about $1^2/_3$ hours, with the flight altitude increasing gradually to 76,000 ft as fuel is burned. These flight altitudes are optimums determined on the basis of a compromise between conflicting airframe and engine efficiency trends. If the altitude is increased beyond the optimum, the fuel consumption generally increases because of a loss in engine efficiency. Conversely, reducing the flight altitude generally causes losses in lift-drag ratio which reflect in increased thrust requirements. The major problem in cruise obviously is that of obtaining low fuel consumption both for the optimum profile and also over the range of altitudes likely to be required by traffic control considerations.

Two new problems in the design and operations areas arise in this phase of the flight in connection with the high kinetic energy of the airplane. One is that of finding ways of restarting the inlet-engine combination following flameout or surge without the need for slowing and then reaccelerating, thereby incurring large fuel usage penalties. The other is that of ensuring that the propulsion system will maintain its integrity during emergencies, such as nacelle fires or rough operation, for an unusually extended period of time (up to 10 min) while the airplane is being slowed to low speeds.

Still another problem area occurs in connection with an emergency such as slow depressurization or air-conditioning failure which requires the airplane to complete its flight at low altitudes and consequently at subsonic speeds. In this event, it is desirable that the efficiency of the airframe-engine combination in this off-design subsonic flight condition be high enough to enable the airplane to fly to its destination.

Let-down is initiated at the end of cruise by throttling the engines to the minimum permissible operating thrust and then descending at the glide angle for maximum range. The airplane can be made to decelerate through sonic speed at an altitude in the vicinity of 60,000 ft, so that intense sonic booms on the ground probably can be avoided. Problem areas are engine operating stability in a highly throttled operating condition, fuel heating associated with the use of the fuel as a heat sink during a period of reduced fuel flow, compressor whine during landing, landing distance and speed, and the extremely large amount of fuel reserves required. These fuel reserves have not been established for supersonic transports. Present jet transport requirements have been assumed which provide for an additional 250-nm cruise at start of let-down plus a 10 percent increase in trip time (windage allowance) plus a 30-min hold at 1,500 ft.

Off-Design Efficiency

It will be noted that the problem of off-design operating efficiency is common to all parts of the mission. On analysis, it is found to be every bit as important as the basic cruise efficiency itself. Fig. 5 shows a breakdown of the fuel usage of the airplane for the mission just discussed. Fuel flow rate is plotted against time so that the area under the curve is directly proportional to the amount of fuel used. The rate of fuel usage is very high during climb and acceleration. In fact, almost one third of the total fuel is used here with a distance gained of less than 10 percent of the total trip distance. Obviously, both the airframe and engine configurations must be examined carefully to see if

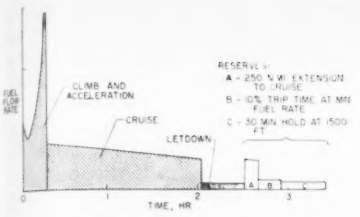

FUEL FLOW RATE
CLIMB AND ACCELERATION
CRUISE
LETDOWN
RESERVES:
A - 250 N MI EXTENSION TO CRUISE
B - 10% TRIP TIME AT MIN FUEL RATE
C - 30 MIN HOLD AT 1500 FT
TIME, HR

Fig. 5. Supersonic transport fuel usage (four turbofan engines, advanced aerodynamics).

some means can be found for improving flight efficiency in this phase of the flight.

Approximately one half of the fuel is utilized during cruise. Thus, any change made to improve off-design operation must be such as not to penalize the specific fuel consumption in cruise.

The fuel used during let-down is fairly small. The loiter and reserve fuels, however, add up to a total approaching the payload of the airplane. Inasmuch as each pound carried displaces 1 lb of payload or increases the take-off gross weight by 2 to 6 lb, it can be seen that this tanker function of the airplane is a very expensive affair. It is essential that means be found for improving engine efficiency in this mode of off-design operation in addition to trying to minimize the total fuel reserve requirements by improving traffic control and operating techniques.

Take-Off and Landing Performance

It is anticipated that substantial increases compared to present jet transport requirements in either airfield length or airplane speed on the runway will be opposed strongly by both the airlines and the airport operators. Some proposed supersonic transport designs do not appear capable of meeting the desired standards in these respects because their low-aspect-ratio wings simply cannot provide adequate levels of lift coefficient and lift-drag ratio. Increasing the installed thrust improves the take-off distance for these machines but generally does not affect landing distance or runway speed. Fortunately, recent research has shown that major reductions in lift-off and touchdown speeds and significant increases in low-speed lift-drag ratio can be attained through the application of variable-wing geometry concepts. These gains automatically also reduce runway length requirements.

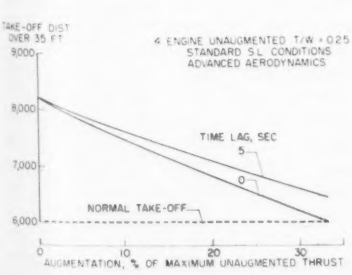


Fig. 6. Effect of thrust reserve on take-off distance (one of four turbofan engines lost at V_1).

It will be pointed out later that the supersonic transport airplane generally will require some means of thrust augmentation for high-altitude acceleration, but will not utilize this augmentation in normal take-offs because of the take-off noise problem. If this capability exists, the required runway length acceptable from the viewpoint of safety can be further reduced by utilizing the thrust augmentation capability of the engines as a reserve. A calculation of the approximate magnitude of the gain obtained with this scheme is shown in Fig. 6. In this calculation it is assumed that the airplane is equipped with four turbofan engines which provide an unaugmented thrust-to-weight ratio of 0.25. It takes off without fan burning because of noise considerations, but with some sort of pilot light operating in the fan ducts so that fan-burning augmentation can be obtained rapidly if needed. It also is assumed that one engine is lost at V_1, which for the purpose of this discussion can be considered to be merely the maximum speed at which the pilot can bring the airplane to a halt within the rest of the available runway length. The other three engines are then brought up to full augmentation, and the take-off is completed.

The take-off distance to 35 ft altitude is plotted against the thrust augmentation capability, expressed as a percent of the maximum unaugmented thrust, for time lags for thrust buildup of zero and 5 sec. With a thrust augmentation capability of $33^1/_3$ percent and zero time lag, there is of course no increase in the take-off distance. The take-off distance required increases as the thrust augmentation capability is reduced and as time lags are introduced, but remains much shorter than that for the unaugmented case over a broad range of conditions. Thus, the scheme appears to be of interest if it can be incorporated in the propulsion system without introducing other penalties.

It is highly probable that thrust reversers will be demanded by the airlines to assist the brakes in slowing and controlling the supersonic transport after landing touchdown or in the case of a take-off abort. If this turns out to be the case, the designer will be confronted with a difficult problem—that of finding means of incorporating such devices in the propulsion system without large increases in weight or prohibitive losses in efficiency of the necessarily sophisticated variable-geometry supersonic nozzles. This difficult design problem places a premium on reducing airplane touchdown and take-off speeds as much as possible by aerodynamic means so that the thrust reverser performance requirements can be minimized.

Noise

ne Oof the significant problem areas with present-day jets is that of noise generated in the vicinity of the airport. Some information[2] on take-off noise along the flight track of the airplane is given in Fig. 7. The perceived noise level in decibels is plotted here against the horizontal distance from the point of lift-off in miles. The horizontal line corresponds to 112 PN db, which has been judged by some authorities to be an acceptable noise level in communities for daylight and early evening take-offs. A somewhat lower level is desirable for operations at night. The densely shaded region encompasses the range of noise levels that have been measured by the firm of Bolt, Beranek and Newman, Inc., for 707-120 aircraft powered by four J57 engines with noise suppressors. The thrust of these machines is in the vicinity of 48,000 lb, and the angle of climb averages approximately 5°. It can be seen that the noise generated by these machines exceeds the arbitrary acceptable level at distances closer than $2^1/_2$ to $3^1/_2$ miles from lift off.

The two dashed lines represent cal-

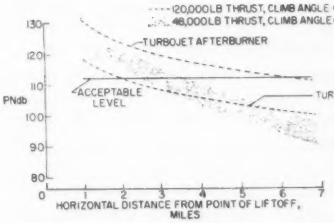


Fig. 7. Noise during climb out.

culations of the noise level that would be measured on the ground for a typical four-engine supersonic transport with 120,000 lb of thrust climbing out at an angle of 10°. The upper line applies to this machine equipped with afterburning turbojet engines and the lower to the same machine with turbofans. It is indicated that the afterburning turbojet machine does not reach the acceptable level of ground noise until it has traveled approximately twice as far from the point of lift off as the subsonic machine. In most present airport situations, such an increase

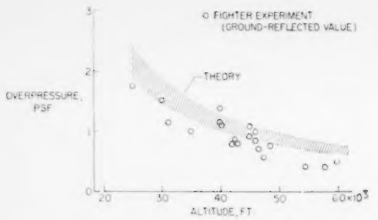


Fig. 8. Sonic boom overpressure correlation (M range 1.2–2.0).

in noise would be intolerable. A supersonic transport with nonafterburning turbojet engines would lie somewhere between the two dashed curves and would be expected to be somewhat noiser than present machines because the absolute thrust is greater, and because noise suppressors for turbojet engines with convergent divergent supersonic nozzles do not presently appear attainable. The turbofan engine, on the other hand, is indicated to offer some possibility of actual improvement. The use of such engines coupled with variable-geometry airframes designed to minimize the ground roll at present appears to be a promising approach to attaining low take-off noise levels. Inasmuch as airport operators and civic organizations maintain strongly that the present jets are too noisy and that they will not permit any further increases, the potential noise reduction of the turbofan engine is a powerful argument for its use.

An even more difficult noise problem is that associated with the sonic boom—that is, the explosive-type pressure rise that occurs at the ear of the observer as the shock-wave system of the airplane passes his position. A summary of measurements of sonic-boom intensity obtained in two NASA programs[3,4] is shown as Fig. 8. The overpressure measured by instruments located at ground level beneath or near the flight track is plotted against the flight altitude of the airplane. The symbols present data obtained in overflights by F-101 and F8U-3 airplanes, and the shaded band represents corresponding theoretical calculations[5] that consider both volume and lift effects. It will be noted that there is considerable scatter in the data, but the favorable effect of increasing altitude is clear. Also, a comparison of experiment and theory indicates that the actual sonic boom tends to be somewhat lower than the theoretical value. This decrease may be due in part to rounding off of some of the peaks of the airplane's ground pressure signature and, at the highest altitudes, to atmospheric attenuation. The rapid fall off of the sparse data points at the highest altitudes lends some hope that atmospheric attenuation may prove to be an important favorable factor. A joint FAA, USAF, NASA program utilizing B-58 airplanes is now under way to obtain more definitive data at high altitudes and at high gross weights.

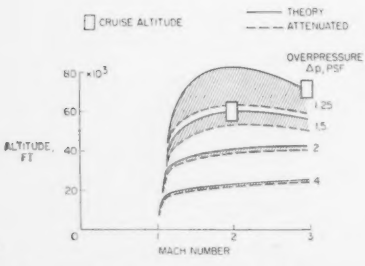


Fig. 9. Estimated transport sonic boom overpressures (W = 325,000 lb; level unaccelerated flight; reflect. coeff., 1.75).

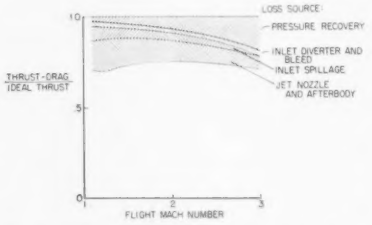


Fig. 10. Engine installation effects (stratosphere components optimized for cruise).

In order to relate these sonic boom measurements to the design problem, the experimental results (Fig. 8) have been correlated and then extrapolated by means of the theory to the transport case (Fig. 9). Contours of sonic-boom overpressures at the ground (including a ground reflectivity factor of 1.75) for a 325,000-lb airplane passing directly overhead in steady level flight are plotted here as a function of altitude and Mach number. It must be emphasized that this chart, because of the lack of data at Mach 3 at heavy airplane weights and at altitudes near 70,000 ft, cannot be considered to be quantitatively accurate and represents only the best possible estimate at the moment. The numbers finally determined may be somewhat different, but the qualitative conclusions regarding engine requirements should not be changed.

The significance of the bands is as follows. A sonic boom with an overpressure of 1 psf resembles distant thunder and should cause negligible public reaction. A boom of 2 psf, on the other hand, may begin to cause occasional nuisance damage such as the breakage of large improperly installed windows, and is almost certain to provoke strong public reaction if the airplane is flown over populated regions. It is not possible at this time to establish limiting permissible values. It would seem, however, that the maximum tolerable value might be in the vicinity of $1^1/_2$ psf. If this turns out to be the case, it appears that there will be little if any problem in the cruising part of the flight of a $M = 3$ airplane—i.e., at 67,000 to 76,000 ft. A Mach 2 cruise airplane, however, is more marginal because its cruising altitude is about 10,000 ft lower. The difference in boom overpressure of about 1/4 psf may prove to be a valid reason for choosing a Mach 3 cruise condition in preference to Mach 2.

Both $M = 3$ and $M = 2$ cruise machines are in serious trouble during altitude acceleration. In order to avoid exceeding the previously mentioned tentative limit of $1^1/_2$ psf, the airplane would have to fly at approximately 42,000 ft at Mach 1.2 and climb to 50,000 at 1.4. This is a difficult requirement that may very well determine the design of both the airframe and engine. A solution for the supersonic transport appears to lie in two directions: (1) that of decreasing the drag to lift of the airframe through increasing the aspect ratio; and (2) that of providing a much greater thrust augmentation capability than exists at present for conventional turbojet engines. Again, the turbofan seems to offer important possibilities for improvement because of its very high airflow.

Installation Losses

The performance of the engine during climb and acceleration is of course a function of more than just gas generator performance alone. Installation losses (Fig. 10) also are a major factor. The net propulsive force of the engine nacelle expressed in terms of the ideal gas generator thrust is shown plotted against Mach number. The installation is optimized for a cruise Mach number of 3. Loss items considered are inlet pressure losses, inlet diverter and boundary-layer bleed drag, inlet spillage drag, and nozzle inefficiency plus nacelle afterbody drag. The main point to be noted is that despite the high level of pressure recovery available, the overall efficiency of this particular installation is lower at transonic speeds than at the $M = 3$ cruise speed. Some improvement undoubtedly can be obtained by designing some of the components for a compromise Mach number. This improvement is limited, however, inasmuch as even a very small degradation of cruise fuel consumption cannot be tolerated. A great deal of work ap-

pears to be needed in order to develop air-inlet and jet-exit configurations which will provide near-optimum performance over the entire speed range.

Airframe-Engine Matching

The airframe-engine matching situation is summarized in Fig. 11. Available thrust and airframe drag, both expressed in terms of take-off weight, are presented as a function of flight Mach number for several of the important operating conditions of the typical flight profile discussed previously (Fig. 4). As shown at the bottom of the figure, the airplane in the initial leg of the flight is assumed after climb out to accelerate to $M = 0.7$ at 7,500 ft, to climb to 40,000 ft at $M = 0.9$, and then to climb gradually while accelerating to the initial cruise speed and altitude.

The solid line at the top of the lower shaded region gives the estimated drag for this configuration during acceleration, with the abrupt dip in the curve being associated with the climb to altitude. The circular symbols identify estimated drags for the initial cruise, altitude hold, and sea-level hold conditions as specified in Figs. 4 and 5. The two shaded regions represent the levels of thrust obtainable by typical turbojet and turbofan engines matched to this airframe with a nonaugmented take-off thrust-to-weight ratio of 0.31. The band on the left is for unaugmented operation; the other band is for full augmentation; and the downward jog between the two bands is again associated with the climb to altitude.

The most significant thing shown in Fig. 11 is the fact that the thrust-minus-drag margin is a minimum at transonic speeds and is much smaller than the margin which exists at either subsonic or supersonic speeds. This matching situation is completely different from that for military aircraft because of more stringent civil restrictions with regard to sonic boom and, as pointed out previously, is expected to have a dominant influence on engine sizing and design.

Also shown in this figure is the fact that both the sea-level and altitude holds are necessarily executed at very low percentages of the available unaugmented thrust, accounting in large part for the high specific fuel consumption encountered in these flight conditions and the consequent large fuel reserves required (Fig. 5). Any other off-design subsonic cruise would suffer from the same thrust-drag mismatch.

One favorable factor arising from the type of airframe-engine matching shown is that the thrust available with a conventional engine greatly exceeds the airframe drag at the cruise Mach number. Thus, such an engine can be operated in cruise at low augmentation temperatures to conserve engine life.

An analysis of Fig. 11 indicates that the first step toward improving the overall airframe-engine matching characteristics should be in the direction of trying to find means at transonic speeds for reducing the aerodynamic drag and obtaining extremely high degrees of thrust augmentation. If this step is successful, the second step logically then should be that of trying to find aerodynamic means for reducing the take-off thrust requirement. This change would permit the use of smaller and lighter gas generators and would improve airframe-engine thrust matching, thus reducing engine specific fuel consumption in the hold and subsonic cruise flight conditions.

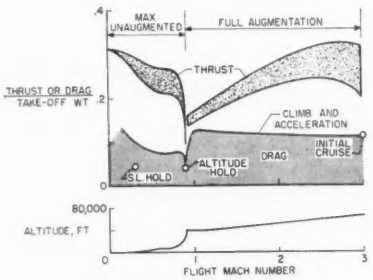


Fig. 11. Airframe-engine matching.

Summary of Requirements

On the basis of the preceding discussion, the special requirements of the engine of the supersonic transport can now be enumerated (Fig. 12). First, low jet velocities or greatly improved noise suppressors are needed to maintain take-off noise levels no higher than for the present jets. Second, a very high degree of thrust augmentation, or actually some form of supercharging, is required to permit acceleration through the transonic range at altitudes high enough to avoid unacceptably intense sonic booms on the ground. Third, inasmuch as weight is very critical, the engine must be light and the cruise specific fuel consumption must be appreciably lower than for present supersonic dash-type machines. Fourth, both the engine and airframe efficiencies must be high in off-design operation, such as hold and subsonic cruise, because of the extreme importance of such operations with regard to fuel reserve requirements and flexibility of route structure. Fifth, the engine must operate at conservative temperatures and stress levels in order to provide reliability, durability, and life competitive with the engines of present transport aircraft. Although

- TAKE-OFF NOISE NO HIGHER THAN FOR PRESENT JET TRANSPORTS
- VERY HIGH DEGREE OF AUGMENTATION FOR TRANSONIC ACCELERATION AT HIGH ALTITUDES
- LOW ENGINE WEIGHT AND CRUISE SFC LOWER THAN FOR PRESENT SUPERSONIC-DASH AIRPLANES
- HIGH EFFICIENCY OVER VERY BROAD RANGES OF OFF-DESIGN OPERATING CONDITIONS
- RELIABILITY, DURABILITY, AND LIFE COMPETITIVE WITH ENGINES OF PRESENT JET TRANSPORTS

Fig. 12. Special requirements of supersonic transport engine.

not listed, it is probably mandatory that the engine incorporate a thrust reverser; it also would be desirable to have the engine designed so that the thrust augmentation would be available for emergency use during take-off.

Possible Engine Configurations

It is essential to recognize that the propulsion system selected must meet all the requirements listed in Fig. 12 with no outstanding deficiencies. Some engines with this potential capability are illustrated in Fig. 13.

The low-bypass-ratio type of turbofan (B.P.R. = 0.5 to 1) is at present being studied by several engine manufacturers. Because of its large airflow, it affords low take-off noise in unaugmented operation and higher efficiency than the turbojet in holding and subsonic cruise. The use of a duct burner, as illustrated, or a full mixed-flow afterburner is a necessary feature to provide adequate cruise thrust as well as thrust augmentation needed for transonic acceleration at high altitudes. On the debit side is the fact that the engine tends to be heavier and have a somewhat higher cruise fuel consumption than a turbojet designed for the same cruise thrust.

The turbofan-jet is a hybrid system of interest for machines that cruise at Mach 3 or above. Essentially it combines the low-speed characteristics of the high-bypass-ratio turbofan with the high-speed characteristics of the ramjet. Inasmuch as the very high bypass ratio provides a tremendous amount of transonic thrust augmentation and thus permits use of a relatively small primary-cycle gas generator, airframe-engine matching is better than that for

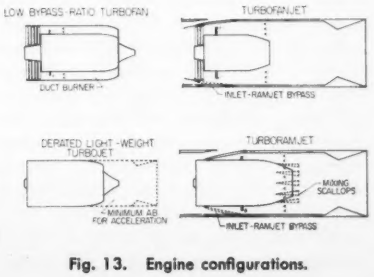


Fig. 13. Engine configurations.

the low-bypass-ratio turbofan in subsonic flight.

At high levels of fan duct temperature, the specific fuel consumption of the turbofan-jet is higher at low supersonic speeds than that for either the low-bypass-ratio turbofan or the nonafterburning turbojet, but appears to become superior to that for either of these engines somewhere in the Mach 3 to 4 range. Near Mach 3, the performance of the fan duct, which dominates the cycle, is relatively insensitive to moderate variations in the pressure rise supplied by the turbofan component. Hence, significant reductions can be made in the fan's turbine inlet temperature during cruise to improve its life and reliability without excessive penalty in overall engine specific fuel consumption. At Mach numbers above about 3.5, it appears that acceptable overall performance can be obtained with the fan shut down completely and windmilling. In this case, it will probably be necessary, as illustrated, to bypass some air around the fan directly to the tailpipe burner.

The possible advantages of the turbofan-jet relative to the low-bypass-ratio turbofan for a Mach 3 application then are improved airframe-engine matching in subsonic operations, increased rotating machinery life, and greater growth potential with respect to cruise speed. The corresponding disadvantages are higher fuel consumption in supersonic climb and acceleration, which may be offset by improved subsonic efficiency, and reduced take-off thrust. At the present time, choice of the turbofan-jet implies the use of an airframe with somewhat better take-off lift coefficient and lift-drag ratio than is necessary for the airframe powered by the other engine. The use of variable-wing sweep and other forms of variable-wing geometry presently seems to offer significant improvement in this area compared to current low-aspect-ratio airframe designs. If the gain is large enough, still other propulsion systems become possible.

Current work on lightweight engine components lends hope that low-pressure-ratio turbojets can be built in the next few years with thrust-to-weight ratios of 8 or more and cruise specific fuel consumptions at $M = 3$ of the order of 10 percent lower than that for the low-bypass-ratio turbofan. Because of the very light weight of these engines, an excess amount of thrust can be provided. Assuming variable-geometry airframe aerodynamics, the engine can then be operated at low power settings during take-off to obtain low take-off noise. The large airflow capacity automatically provides good performance in acceleration if afterburners are incorporated. The major problems with this configuration appear to be those of attaining efficient operation in subsonic cruise and hold and of attaining a combination of low specific fuel consumption and acceptable turbine inlet temperatures in cruise (afterburners either not lit or operating at a low reheat temperature). The specific fuel consumptions in the first two operating conditions are very high because of airframe-engine mismatch even if several of the engines are shut down completely. It is emphasized that, regardless of whether or not these problems can be solved, the successful application of this engine continues to be dependent on the attainment of advanced airframe take-off aerodynamics in conjunction with the attainment of engine thrust-weight ratios approximately twice present values.

	4 LBR TURBOFANS	4 TURBOFANJETS	6 LT WT TURBOJETS [1]
RATED AIRFLOW, LB/SEC	600	600	300
T.O NOISE REL. TO SUBSONIC JET [2], ΔDB	-3	-6	0
T.O. DIST. OVER 35 FT ON HOT DAY, FT	5,800	6,300	7,300
M = 1.1, MAX. ALT. FOR 0.5 FT/SEC² LEVEL ACCEL., FT	40,000	45,000	42,000
SFC M = 1.1 ACCEL	1.61	2.15	2.20
SFC CRUISE	1.60	1.55	1.65
SFC S.L. HOLD	1.18	1.00	1.73
AIRPLANE T.O. WT., LB [3]	386,000	350,000	398,000

① WITH A/B FOR ACCEL. ONLY
② WITH FOUR SUPPRESSED J57 ENGINES
③ ACCEL. THROUGH M = 1.1 @ 40,000 FT

Fig. 14. Engine performance studies (M = 3.0 cruise; 30,000-lb payload; 3,500 nm; adv. airframe).

The last engine configuration shown, the turboram-jet, combines the bypass feature of the turbofan-jet with the gas generator of the lightweight turbojet. Its main advantages are increased engine life and increased cruise Mach number capability. If, as indicated by the dotted "mixing scallops," a satisfactory ejector system can be developed for the take-off condition, sufficient noise suppression may be attained to permit operation at an appreciably higher percentage of the take-off thrust rating. If so, the amount of installed gas generator thrust can be reduced compared to the previous case, provided the transonic acceleration problem is not limiting.

Another arrangement, not shown, is the frequently proposed solution of a turbojet or turbofan booster system combined with a completely separate ram-jet system for cruise. The ram-jets can be either fixed geometry if used only in the vicinity of the design cruise Mach number or variable geometry if required to assist the turbine-engine booster system during a significant part of the supersonic acceleration. Because of the efficiency characteristics of the unsupercharged ram-jet, it is anticipated that the minimum cruise Mach number for this arrangement will be appreciably higher for an arbitrary minimum value of range efficiency factor than those for the dual-purpose engine configurations. The attractiveness of this booster-plus-ram-jet solution to the overall problem depends primarily on the ability of the airplane designer to incorporate the two large essentially independent propulsion systems into one airframe without incurring significant drag, weight, or system complexity problems.

Mission Performance

Characteristics of a low-bypass-ratio turbofan, a turbofan-jet, and a derated lightweight turbojet with an acceleration afterburner have been estimated by cycle calculation procedures and correlations of available data[6–8] to obtain a preliminary indication of the level of airplane performance possible in a Mach 3 cruise mission. Similar calculations were not attempted for the other two systems because of the difficulty of estimating ejector-performance and airframe-drag effects to the degree of accuracy required for meaningful comparison.

The airplane considered (Fig. 14) was assumed to fly the mission of Fig. 4 with a 30,000-lb, 125-passenger payload and to have an advanced variable-geometry airframe capable of a cruise lift-drag ratio of 7.3. This airframe was equipped alternately with four 600-lb/sec-airflow low-bypass-ratio turbofans, four 600-lb/sec turbofan-jets, and six 300-lb/sec lightweight afterburner-equipped turbojets. Airframe drag was assumed to be unaffected by the changes in engine configuration, but appropriate changes were made in airplane empty weight.

According to the calculations summarized in Fig. 14, the jet noise at the airfield and beneath the take-off path of the airplane would be significantly lower for both of the fan-engine configurations than for present subsonic jets with suppressed J57 engines. The jet noise for the turbojet configuration is shown to be the same as for the present jets because this particular propulsion system was sized to meet this condition.

The low-bypass-ratio turbofan is shown to offer somewhat better take-off than the other propulsion systems. All systems are acceptable by present standards, however, especially if the additional thrust available can be used in an emergency. All three

configurations also appear to provide acceptable altitudes for transonic acceleration.

The specific fuel consumptions for the three propulsion systems are indicated to differ appreciably in different parts of the mission, as would be expected. The integrated results of these differences show up as differences in airplane take-off weight. From a comparison of these weights, the turbofan-jet appears to be best for this particular mission by a rather wide margin, with the other turbofan second, and the derated turbojet third. It is clear that less advanced turbojets and afterburning turbojets, such as those at present in the advanced hardware development stage, are not likely to provide an acceptable level of mission performance.

An overall assessment of the background calculations of the present analysis indicates that the low-bypass-ratio turbofan may be the best all-around power plant for a supersonic commercial air transport designed for cruise Mach numbers up to about 2.5. For cruise Mach numbers of 3 and above, however, it appears that the best arrangement very likely will combine features of both the turbofan and the ram-jet, possibly in the form of the turbofan-jet. Extensive analysis will be required to pin down the exact details of the hybrid configuration which will be optimum from the point of view of mission flexibility, engine life, and speed growth potential in addition to just mission efficiency alone as considered here.

Concluding Remarks

In summary, the propulsion system requirements of the supersonic commercial air transport are much more stringent than those for supersonic military aircraft in the areas of take-off noise, sonic boom, off-design operating efficiency, and engine life. Engines currently under development do not appear capable of meeting all of the essential requirements, although some of their components and technical advances being made in the course of their development are applicable to the problem. On the basis of this particular study, the low-bypass-ratio turbofan appears to be the best all-around power plant for cruise Mach numbers up to about 2.5. For cruise Mach numbers of 3 and above, it is believed that the optimum propulsion system very likely will combine features of both the turbofan and the ram-jet, possibly in the form of the turbofan-jet.

✦ ✦ ✦

References

[1] Anon., *Commercial Supersonic Transport Aircraft Report*, Federal Aviation Agency, Dec. 1960.

[2] Staff of Langley Research Center, *The Supersonic Transport—A Technical Summary*, NASA TN D-423, June 1960.

[3] Maglieri, Domenic J., Hubbard, Harvey H., and Lansing, Donald L., *Ground Measurements of the Shock-Wave Noise From Airplanes in Level Flight at Mach Numbers to 1.4 and at Altitudes to 45,000 Feet*, NASA TN 48, 1959.

[4] Lina, Lindsay J., and Maglieri, Domenic J., *Ground Measurements of Airplane Shock-Wave Noise at Mach Numbers to 2.0 and at Altitudes to 60,000 Feet*, NASA TN D-235, 1960.

[5] Walkden, F., *The Shock Pattern of a Wing-Body Combination Far From the Flight Path*, Aeronautical Quarterly, Vol. IX, No. 2., pp. 164–194, May 1958.

[6] Jamison, R. R., and Lane, R. J., *Engines for Supersonic Air Liners*, Journal of RAeS, Vol. 64, No. 597, pp. 507–531, Sept. 1960.

[7] Hooker, S. G., *Future of Air-Breathing Engines in Aviation*, Institution of Mechanical Engineers, 1959. (James Clayton Lecture delivered at the Institution, London, Dec. 16, 1959.)

[8] Alford, J. S., *Power Plants for Supersonic Transport*, Journal of RAeS, Vol. 64, No. 598, pp. 617–628, Oct. 1960.

IAS SPECIAL PUBLICATIONS

	Member	Nonmember
Aerospace Engineering Index - 1958	$10.00	$15.00*
Aeronautical Engineering Index - 1956 and 1957 (each)	10.00	15.00*
Aeronautical Engineering Index - 1947 through 1955 (each)	3.00	5.00*
IAS/Army Aviation Meeting Proceedings - 1961 (68 pp.)	2.50	5.00*
National Midwestern Meeting on Air Logistics Proceedings - 1960 (116 pp.)	5.00	10.00*
Weapons Systems Management - National Midwestern Meeting Proceedings - 1957 (60 pp.)	1.50	2.50*
National Symposium on Hypervelocity Techniques Proceedings - 1960 (176 pp.)	5.00	10.00*
Recovery of Space Vehicles Symposium Proceedings - 1960 (104 pp.)	4.00	8.00*
National Specialists Meeting on Dynamics & Aeroelasticity Proceedings - 1958 (136 pp.)	3.50	6.00*
1961 National Telemetering Conference Report	3.50	5.50*
1960 National Telemetering Conference Report	4.50	6.50*
1959 National Telemetering Conference Report	3.00	4.00*
Frontiers of Science & Engineering Symposium Proceedings - 1959 (132 pp.)	5.00	10.00*
Fourth Turbine-Powered Air Transportation Meeting Proceedings - 1959	2.00	4.00*
Second Turbine-Powered Air Transportation Meeting Proceedings - 1955	3.50	6.00*
7th Anglo-American Aeronautical Conference Proceedings - 1959	20.00	25.00*
5th International Aeronautical Conference Proceedings - 1955	15.00	20.00*
2nd International Aeronautical Conference Proceedings - 1949	5.00	5.00*
National Naval Aviation Meeting Proceedings - 1957 (124 pp.)	3.00	5.00*
Index to Books on Selected Technical Subjects in the IAS Library (up to 1950), unbound	2.00	2.00*

* Add $1.00 for orders outside the U.S.A.

These may be obtained by writing to: **Special Publications Dept., IAS, 2 E. 64th St., N.Y. 21, N.Y.**

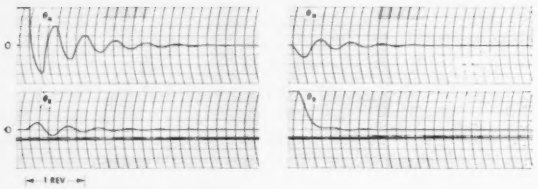


Fig. 2. $C_x = 0.5, C_z = 1.0, Y_o = 0.$

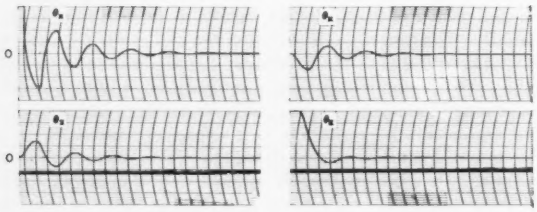


Fig. 3. $C_x = 0.5, C_z = 1.0, Y_o = 0.2.$

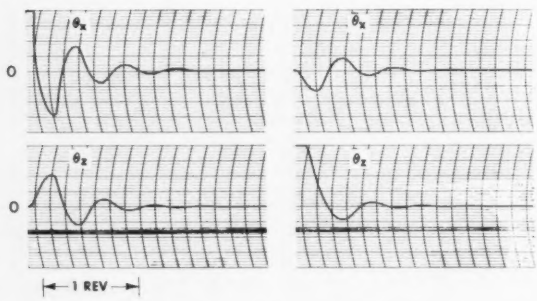


Fig. 4. $C_x = 0.5, C_z = 1.0, Y_o = 0.4.$

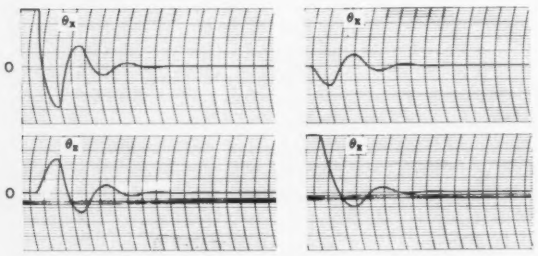


Fig. 5. $C_x = 0.5, C_z = 1.0, Y_o = 0.5.$

Transformation to Rotating Reference Frame

Eqs. (1.1) through (1.6) describe the motion with respect to a Newtonian frame. It is more convenient for design purposes to represent the motion with respect to the rotating reference axis system. This is done by transforming these equations with the aid of the Euler angles shown in Fig. 1.

In doing so, an approximation is made in order that the equations to be analyzed have constant coefficients. It is assumed that the reference frame rotates at a constant angular velocity $\omega_o \hat{e}_{y'}$, the mean angular motion of the satellite, and that the reference frame has no other component of angular velocity. This condition, in actuality, is impossible to satisfy. First, the orbit would have to be circular for the y' component of rotational velocity of the satellite to be constant. Second, the oblateness of the earth prevents the motion's occurring in a true plane during any given complete rotation (except for equatorial and polar orbits) and in addition causes a precession of the line of nodes of the satellite motion. Consequently, instead of the rotation of the reference frame having only a constant angular velocity component $\omega_o \hat{e}_{y'}$, in reality it is composed of this constant component plus small variable components about each of the x', y', and z' axes, which are neglected in the preliminary analysis. The effect of the small variable rotational components, called driving and parametric excitation torques by Roberson,[1] is, in the final analysis, to introduce small variable torques into the equations of motion.

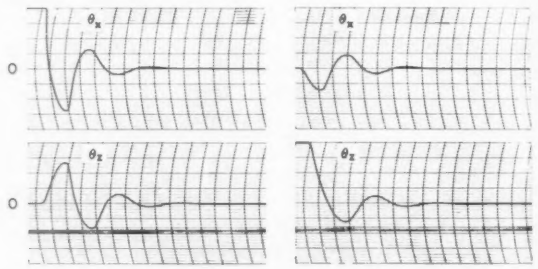


Fig. 6. $C_x = 0.5, C_z = 1.0, Y_o = 0.6.$

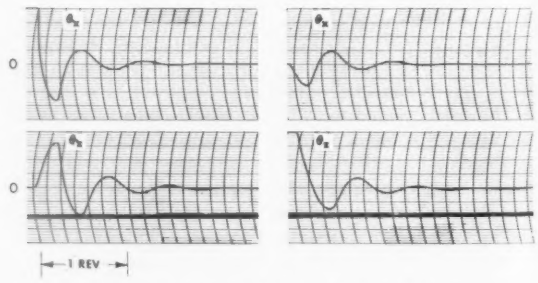


Fig. 7. $C_x = 0.5, C_z = 1.0, Y_o = 0.8.$

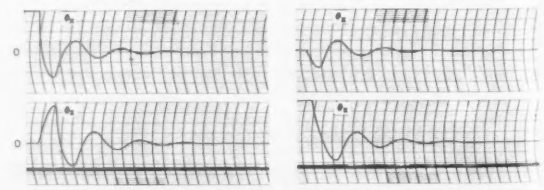


Fig. 8. $C_x = 0.5, C_z = 1.0, Y_o = 1.0.$

Figs. 2–8. Linear response plots (all plots are to same scale).

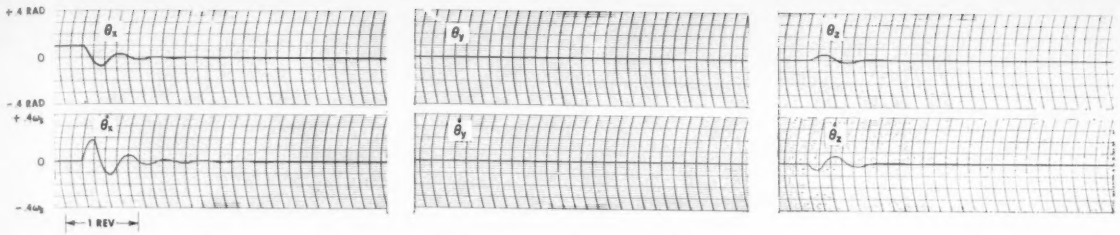


Fig. 9. Initial displacement: $\theta_x\}_0 = 0.1$ radian.

It should be noted that the small variable torques are of such a nature that, to account for their effect upon a given system, one must know the parameters of the particular orbit for which the satellite is intended—i.e., eccentricity, period, argument of perigee, and inclination. Further treatment of these torques exceeds the scope of this investigation.

In transforming the previously derived equations from a Newtonian frame to the rotating reference frame, it is necessary to express the constant rotational component $\omega_s\hat{e}_y'$ in terms of the satellite axis system, arbitrarily displaced as shown in Fig. 1. By means of the Euler angles shown, where the order of rotation is Ψ, Θ, Φ, the following relationship is obtained:

$$\omega_s\hat{e}_{y'} = \omega_s \sin\Psi\cos\Theta\hat{e}_x + \omega_s[\cos\Psi\cos\Phi + \sin\Psi \sin\Theta\sin\Phi]\hat{e}_y + \omega_s[\sin\Psi\sin\Theta\cos\Phi - \cos\Psi\sin\Phi]\hat{e}_z$$

The rotation of the satellite with respect to the Newtonian frame is equal to its rotation with respect to the primed reference axis system plus the rotation of the primed system with respect to the Newtonian frame, expressed in terms of the satellite body axes, as follows:

$$\bar{P} = P + \omega_s \sin\Psi\cos\Theta \tag{1.7}$$

$$\bar{Q} = Q + \omega_s[\cos\Psi\cos\Phi + \sin\Psi\sin\Theta\sin\Phi] \tag{1.8}$$

$$\bar{R} = R + \omega_s[\sin\Psi\sin\Theta\cos\Phi - \cos\psi\sin\Phi] \tag{1.9}$$

where P, Q, and R are angular velocity components on the x, y, and z satellite axes measured with respect to the primed reference system.

The following vector equation relates angular acceleration with respect to the Newtonian frame to that with respect to the reference frame rotating at angular rate $\omega_s\hat{e}_y'$:

$$\left(\frac{d\Omega}{dt}\right)_{\text{Newtonian}} = \omega_s \times \Omega + \left(\frac{d\Omega}{dt}\right)_{\text{Rotating}}$$

where $\Omega = P\hat{e}_x + Q\hat{e}_y + R\hat{e}_z$. This equation is expressed in terms of P, Q, and R and equated to the angular acceleration vector expressed in terms of $\bar{P}$, $\bar{Q}$, and $\bar{R}$ as follows:

$$\begin{aligned}\left(\frac{d\Omega}{dt}\right)_N = {} & \Big\{\omega_s[\cos\Psi\cos\Phi + \sin\Psi\sin\Theta\sin\Phi]\,R - \\ & \omega_s[\sin\Psi\sin\Theta\cos\Phi - \cos\Psi\sin\Phi]Q + \\ & \left[\frac{dP}{dt} + QR - QR\right]\Big\}\hat{e}_x \\ & + \Big\{\omega_s[\sin\Psi\sin\Theta\cos\Phi - \cos\Psi\sin\Phi]P \\ & - \omega_s[\sin\Psi\cos\Theta]R + \\ & \left[\frac{dQ}{dt} + PR - PR\right]\Big\}\hat{e}_y \\ & + \Big\{\omega_s[\sin\Psi\cos\Theta]Q - \omega_s[\cos\Psi\cos\Phi + \\ & \sin\Psi\sin\Theta\sin\Phi]P + \\ & \left[\frac{dR}{dt} + PQ - PQ\right]\Big\}\hat{e}_z \\ = {} & \left(\frac{d\bar{P}}{dt} + \overline{QR} - \overline{QR}\right)\hat{e}_x + \\ & \left(\frac{d\bar{Q}}{dt} + \overline{PR} - \overline{PR}\right)\hat{e}_y + \\ & \left(\frac{d\bar{R}}{dt} + \overline{PQ} - \overline{PQ}\right)\hat{e}_z \end{aligned} \tag{1.10}$$

From this point hence the development will be based upon the assumption of small angular motion

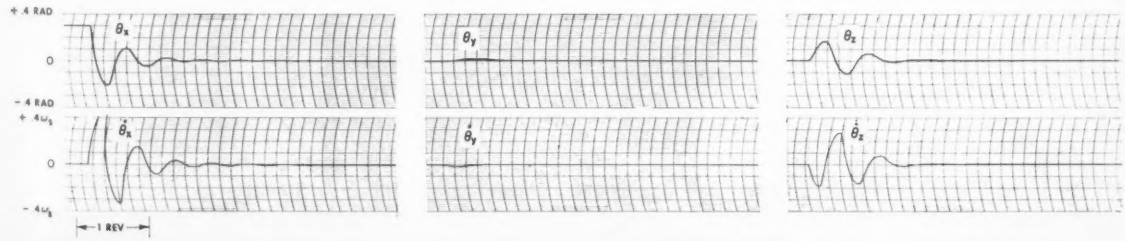


Fig. 10. Initial displacement: $\theta_x\}_0 = 0.3$ radian.

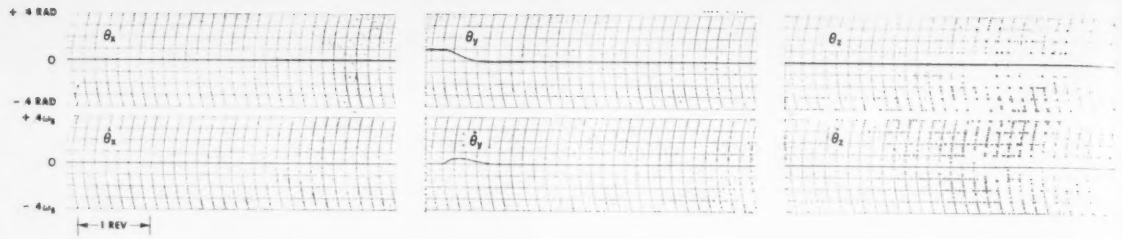


Fig. 11. Initial displacement: $\theta_y\Big\}_0 = 0.1$ radian.

of the satellite with respect to the primed reference axes. This will appreciably simplify the equations and not affect, basically, the generality of the problem, for it is reasonable to assume that the control system must be such as to force the satellite to remain within these bounds. This assumption leads to the introduction of $\theta_{x,y,z}$ as defined below, and the following relationships obtain:

$$\left.\begin{aligned} \Phi &= \theta_x \qquad P = \frac{d\theta_x}{dt} \qquad \frac{dP}{dt} = \frac{d^2\theta_x}{dt^2} \\ \Theta &= \theta_y \qquad Q = \frac{d\theta_y}{dt} \qquad \frac{dQ}{dt} = \frac{d^2\theta_y}{dt^2} \\ \Psi &= \theta_z \qquad R = \frac{d\theta_z}{dt} \qquad \frac{dR}{dt} = \frac{d^2\theta_z}{dt^2} \end{aligned}\right\} \quad (1.11)$$

$$\sin(\Phi, \Theta, \Psi) = \Phi, \Theta, \Psi \qquad \cos(\Phi, \Theta, \Psi) = 1$$

Equating like components appearing on opposite sides of Eq. (1.10) and applying the conditions expressed in Eqs. (1.11) to Eqs. (1.7) through (1.10), the following relationships result:

$$\left.\begin{aligned} \bar{P} &= \frac{d\theta_x}{dt} + \omega_s\theta_z \qquad \frac{d\bar{P}}{dt} = \frac{d^2\theta_x}{dt^2} + \omega_s\frac{d\theta_z}{dt} \\ \bar{Q} &= \frac{d\theta_y}{dt} + \omega_s \qquad \frac{d\bar{Q}}{dt} = \frac{d^2\theta_y}{dt^2} \\ \bar{R} &= \frac{d\theta_z}{dt} - \omega_s\theta_x \qquad \frac{d\bar{R}}{dt} = \frac{d^2\theta_z}{dt^2} - \omega_s\frac{d\theta_x}{dt} \end{aligned}\right\} \quad (1.12)$$

The gravity differential torques for small angular motion are shown in reference 2 to be

$$\left.\begin{aligned} T_{xg} &= -3\omega_s^2(I_y - I_z)\theta_x \\ T_{yg} &= -3\omega_s^2(I_z - I_x)\theta_y \\ T_{zg} &= 0 \end{aligned}\right\} \quad (1.13)$$

Substituting Eqs. (1.4–6) and (1.11–13) into the Euler body-axis Eqs. (1.1–3), these equations are transformed as follows:

$$I_x\left[\frac{d^2\theta_x}{dt^2} + \omega_s\frac{d\theta_z}{dt}\right] - (I_y - I_z)\left[\frac{d\theta_y}{dt} + \omega_s\right] \times \left[\frac{d\theta_z}{dt} - \omega_s\theta_x\right] = -\frac{dH_x}{dt} + H_y\left[\frac{d\theta_z}{dt} - \omega_s\theta_x\right] - H_z\left[\frac{d\theta_y}{dt} + \omega_s\right] - 3\omega_s^2(I_y - I_z)\theta_x + T_{xf} \quad (1.14)$$

$$I_y\left[\frac{d^2\theta_y}{dt^2}\right] - (I_z - I_x)\left[\frac{d\theta_x}{dt} + \omega_s\theta_z\right] \times \left[\frac{d\theta_z}{dt} - \omega_s\theta_x\right] = -\frac{dH_y}{dt} - H_x\left[\frac{d\theta_z}{dt} - \omega_s\theta_x\right] + H_z\left[\frac{d\theta_x}{dt} + \omega_s\theta_z\right] - 3\omega_s^2(I_x - I_z)\theta_y + T_{yf} \quad (1.15)$$

$$I_z\left[\frac{d^2\theta_z}{dt^2} - \omega_s\frac{d\theta_x}{dt}\right] - (I_x - I_y)\left[\frac{d\theta_x}{dt} + \omega_s\theta_z\right] \times \left[\frac{d\theta_y}{dt} + \omega_s\right] = -\frac{dH_z}{dt} + H_x\left[\frac{d\theta_y}{dt} + \omega_s\right] - H_y\left[\frac{d\theta_x}{dt} + \omega_s\theta_z\right] + T_{zf} \quad (1.16)$$

Nondimensionalization

It is evident that these equations should now be simplified as much as possible. This is done by dividing all terms by $I_x\omega_s^2$, effecting a time scale change according to the definition $\tau = \omega_s t$, and applying the following definitions:

$$\tau = \omega_s t, \quad \frac{d}{dt} = \frac{d}{d\tau}\frac{d\tau}{dt}, \quad \frac{d(\,)}{dt} = \omega_s\frac{d(\,)}{d\tau} = \omega_s(\dot{}), \quad \frac{d^2(\,)}{dt^2} = \omega_s^2\frac{d^2(\,)}{d\tau^2} = \omega_s^2(\ddot{})$$

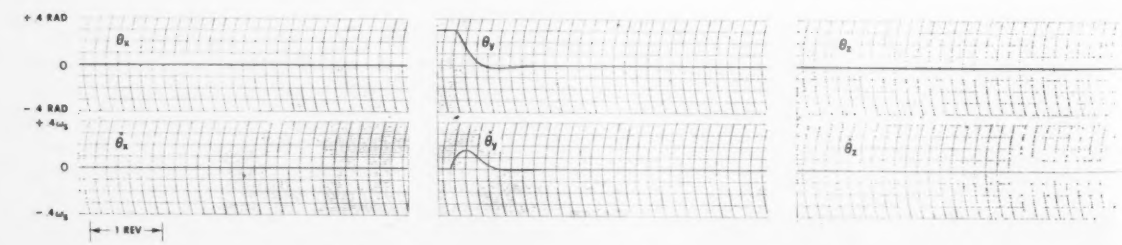


Fig. 12. Initial displacement: $\theta_y\Big\}_0 = 0.3$ radian.

$$I_z/I_x = \alpha \quad I_y/I_x = \beta$$
$$H_x/I_x\omega_s = X \quad H_y/I_x\omega_s = Y \quad H_z/I_x\omega_s = Z$$
$$T_{xf}/I_x\omega_s^2 = L_x \quad T_{yf}/I_x\omega_s^2 = L_y \quad T_{zf}/I_x\omega_s^2 = L_z$$

$$\ddot{\theta}_x + \dot{\theta}_z - (\beta - \alpha)[\dot{\theta}_y + 1][\dot{\theta}_z - \theta_x] = -\dot{X} + Y[\dot{\theta}_z - \theta_x] - Z[\dot{\theta}_y + 1] - 3(\beta - \alpha)\theta_x + L_x \quad (1.17)$$

$$\beta\ddot{\theta}_y - (\alpha - 1)[\dot{\theta}_x + \theta_z][\dot{\theta}_z - \theta_x] = -\dot{Y} - X[\dot{\theta}_z - \theta_x] + Z[\dot{\theta}_x + \theta_z] - 3(1 - \alpha)\theta_y + L_y \quad (1.18)$$

$$\alpha[\ddot{\theta}_z - \dot{\theta}_x] - (1 - \beta)[\dot{\theta}_x + \theta_z][\dot{\theta}_y + 1] = -\dot{Z} + X[\dot{\theta}_y + 1] - Y[\dot{\theta}_x + \theta_z] + L_z \quad (1.19)$$

Linearization

In order to arrive at a logical design scheme, it is necessary to linearize these equations. Linearization is taken about the equilibrium point where all variables have zero values except Y. Y will be allowed to have an equilibrium value if it develops that such would aid in attitude stabilization; however, X and Z cannot be allowed to have equilibrium values other than zero for, if such were the case, the interaction between X, Z, and ω_s would cause a constant torque to be applied on the system. This would require an equal and opposite control torque, meaning that one or more of the rotors would have to be constantly accelerated. It is evident that there is no such interaction between Y and ω_s. The linearized equations appear in Eqs. (1.20–22). The terms have been collected so that only the control and forcing torques appear on the right-hand side of the equation.

$$\ddot{\theta}_x + [4(\beta - \alpha) + Y_o]\theta_x + [1 + \alpha - \beta - Y_o]\dot{\theta}_z = -\dot{X} - Z + L_x \quad (1.20)$$

$$\beta\ddot{\theta}_y + 3(1 - \alpha)\theta_y = -\dot{Y} + L_y \quad (1.21)$$

$$\alpha\ddot{\theta}_z + [\beta - 1 + Y_o]\theta_z - [1 + \alpha - \beta - Y_o]\dot{\theta}_x = -\dot{Z} + X + L_z \quad (1.22)$$

Design Procedure

Forcing Torques

Before discussing the requirements to be placed upon the control system, one must consider the nature and frequency of the torques which cannot be predicted with any great degree of accuracy. An excellent discussion of these torques is contained in reference 1 and is summarized here.

Earth's magnetic field—During any given orbit, the satellite encounters variations in the earth's magnetic field, along each of its axes, which induce eddy currents in the skin and other parts of the vehicle. In turn, the interaction of these eddy currents with the earth's magnetic field causes a torque on the satellite.

A nonspherical body susceptible to magnetization experiences a torque which tends to align its long axis with the earth's magnetic field. The torques produced about the x' and z' axes are of orbital frequency with amplitudes which are functions of twice the earth's rotational frequency. The torque about the y' axis has a basic frequency of twice orbital frequency whose amplitude varies also as a function of twice the earth's rotational frequency.

In addition, there are also torques due to interaction of any permanent magnets within the satellite with the earth's magnetic field.

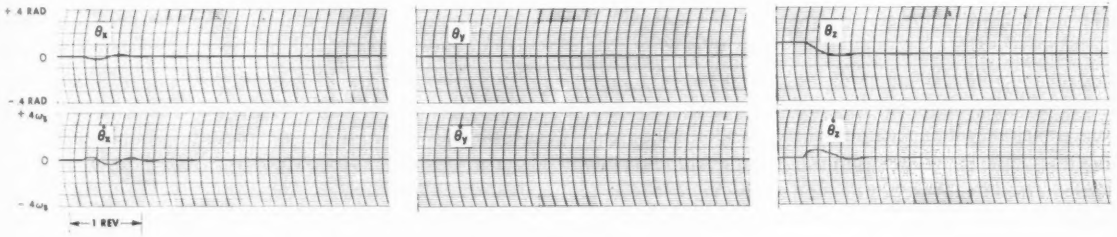


Fig. 13. Initial displacement: $\theta_s\Big\}_0 = 0.1$ radian.

Earth's electric field—A nonspherical satellite experiences a torque which tends to align the vehicle's long axis with the essentially radial electric field of the earth. The effect is similar to that of the earth's gravitational field.

In addition, because the satellite is a conductor traveling at high velocity, an equivalent electric field is produced. The interaction of this electric field with the earth's magnetic field produces a torque on the vehicle.

Solar radiation pressure—The radiation pressure on a black body is approximately 4.3×10^{-5} dyne/cm^2. The torque produced by solar pressure is equal to the product of the radiation pressure and the area presented to the sun times the distance between the centroid of this area and the projection of the center of mass of the satellite on this area. Such torques can be eliminated by careful structural design.

Electromagnetic radiation from satellite—Any asymmetric radiation from the satellite with respect to the satellite center of mass will produce a torque. Again, such torques can be eliminated through careful radiator design.

Aerodynamic drag—At sufficiently low altitudes,

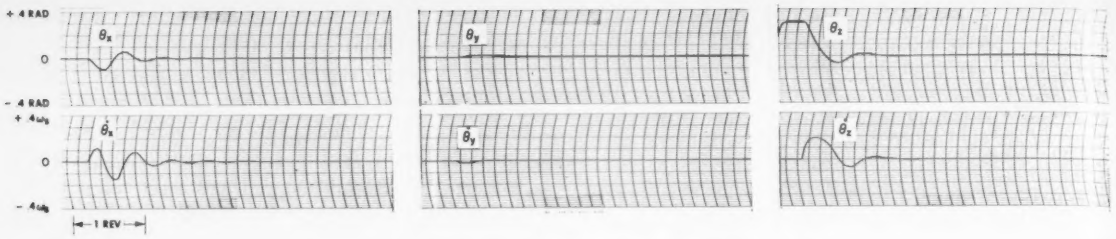


Fig. 14. Initial displacement: $\theta_z\Big\}_0 = 0.3$ radian.

the assumption of free molecular flow gives both a constant torque about the pitch axis and a spring torque about the pitch axis proportional to the pitch angle θ_y for pitching motion about the y-axis where the satellite has a principal moment of inertia about the z-axis and the center of pressure along this axis does not coincide with the center of mass. The constant torque can be eliminated by proper positioning of the center of mass with respect to the center of aerodynamic pressure.

Meteorite bombardment—The frequency and magnitude of impulses caused by meteorite bombardment are difficult to predict although more and more information is being gained through satellite experiments. The frequency and magnitude will certainly depend upon the size and shape of the vehicle. It is believed that impacts will cause transient oscillations which are large compared with those caused by other sources mentioned here.

Moving parts in the satellite—These torques are exceedingly difficult to analyze. Their source may be circulating fluids, vibrating parts, moving parts, rotating wheels, etc., which produce torques through gyroscopic coupling, inertial reaction, center of mass shift, shift of axes of inertia, etc. Some of the effects may be quite significant.

Other gravitational fields—Gravity differential torques due to other celestial bodies can be found in a manner identical to that utilized in finding the differential torques due to the earth. The differential torques due to the sun and moon have been found to be nine orders of magnitude less than those due to the earth.

Earth's gravitational field—The dominant terms of the gravity differential torques are given by Eqs. (1.13). The source of these torques can best be illustrated by considering a "dumbbell" configuration consisting of two masses connected by a weightless rod. The mass nearest the earth experiences a greater gravitational force than does the other mass. This differential gravity force produces a spring torque tending to align the long axis with the gravitational vector. As stated in reference 1, the complete expression for this torque contains 23 terms other than the dominant terms given in Eqs. (1.13); these 23 include terms of second order and higher in the attitude deviation angles and their derivatives, the earth's oblateness, orbital ellipticity, etc. These additional terms give small driving functions of time and parametric excitation terms involving the deviation angles and their rates.

Response Requirements

From the foregoing discussion of forcing torques, it is apparent that this is an area worthy of much study in itself. It would appear that one should base the design primarily upon (1) the expectation of forcing torques of orbital frequency resulting both from external sources as previously outlined and from the driving and parametric excitation terms and (2) impulsive displacements caused by meteorite bombardment.

Accordingly, the system should exhibit good transient response to the impulsive torques due to meteorite bombardment and operate so that the applied torques of orbital frequency do not disturb the system excessively.

Analytical Procedure

A proper basis of design will be to arrive at a satisfactory control scheme based upon the solution of the linearized Eqs. (1.20–22) by means of analog computer simulation. Then by use of this control system, computer solutions of Eqs. (1.17–19), the nonlinear equations for small angular displacements, can be obtained and any necessary control system adjustments made. The complete design analysis would then include the solution of the exact equations of motion, unrestricted by the assumption of small angular motion, to include the effects of the small driving and parametric excitation terms. These equations can be obtained by the exact Euler angle transformations. The latter step exceeds the scope of this investigation.

Investigation of Noninteracting Controls

Analysis of Linearized Equations

As stated previously, the first step in a logical design procedure is the solution of the linearized equations of motion, Eqs. (1.20–22). With the use of operator notation, where $p = d/dt$, and by definition of a satellite inertia parameter σ, where $\sigma = \beta - \alpha - 1$, the linearized equations become

$$(p^2 + 4\sigma + Y_o + 4)\theta_z - (\sigma + Y_o)p\theta_z = -\dot{X} - Z + L_z \quad (3.1)$$

$$(\beta p^2 - 3\alpha + 3)\theta_y = -\dot{Y} + L_y \qquad (3.2)$$

$$(\alpha p^2 + \alpha + \sigma + Y_o)\theta_z + (\sigma + Y_o)p\theta_x = -\dot{Z} + X + L_z \qquad (3.3)$$

Note that in the linearization process, Eq. (3.2), describing motion about the y-axis, has become decoupled from the other two equations. Thus the primary effort in developing a workable control scheme will be directed toward solution of the equations which remain coupled, Eqs. (3.1) and (3.3). Note also that coupling occurs both in the satellite dynamics, represented by the terms on the left side of the equations, and in the control dynamics, represented by the terms on the right side of the equations.

Uncoupled Response

It would be highly desirable to decouple Eqs. (3.1) and (3.3) through proper control system design so that any motion about either the x- or z-axis would not disturb the other. With such a control system configuration, it is much simpler to devise an optimum control scheme and to predict its response characteristics than for the case where the two equations were to remain coupled. In developing the relationships which permit decoupling, both X and Z are permitted to be functions of both θ_x and θ_z as follows:

$$\left.\begin{aligned} X &= C_{11}\theta_x + C_{12}\theta_z & Z &= C_{21}\theta_x + C_{22}\theta_z \\ \dot{X} &= C_{11}p\theta_x + C_{12}p\theta_z & \dot{Z} &= C_{21}p\theta_x + C_{22}p\theta_z \end{aligned}\right\} \qquad (3.4)$$

where the C_{ij}'s can be any desired operators to be chosen after the conditions effecting decoupling have been specified and decoupling has been accomplished.

In the usual control scheme, the controls are normally specified as functions of the errors in the elements being controlled. This is true here also, although not so readily apparent. The choice of the reference axis system has been such that the command input signal for all three axes is zero for all angles and their derivatives at all times. Thus $C_{ij}\theta$ is equivalent to $-C_{ij}\epsilon_\theta$, where, as in servomechanism theory, ϵ_θ equals θ_i (command input) minus θ_o (system output).

With the control system as defined here, the equations of motion are

$$(p^2 + 4\sigma + Y_o + 4)\theta_x - (\sigma + Y_o)p\theta_z = -C_{11}p\theta_x - C_{12}p\theta_z - C_{21}\theta_x - C_{22}\theta_z + L_x \qquad (3.5)$$

$$(\alpha p^2 + \alpha + \sigma + Y_o)\theta_z + (\sigma + Y_o)p\theta_x = -C_{21}p\theta_x - C_{22}p\theta_z + C_{11}\theta_x + C_{12}\theta_z + L_z \qquad (3.6)$$

The requirement of uncoupled response places the following conditions on the control system:

$$(\sigma + Y_o)p\theta_z = C_{12}p\theta_z + C_{22}\theta_z$$
$$(\sigma + Y_o)p\theta_x = -C_{21}p\theta_x + C_{11}\theta_x$$

These conditions specify C_{22} in terms of C_{12} and C_{11} in terms of C_{21} as follows:

$$C_{22} = (\sigma + Y_o - C_{12})p \qquad (3.7)$$

$$C_{11} = (\sigma + Y_o + C_{21})p \qquad (3.8)$$

Substituting these conditions back in to Eqs. (3.5) and (3.6),

$$(p^2 + 4\sigma + Y_o + 4)\theta_x - (\sigma + Y_o)p\theta_z = -(\sigma + Y_o + C_{21})p^2\theta_x - C_{12}p\theta_z - C_{21}\theta_x - (\sigma + Y_o - C_{12})p\theta_z + L_x$$

$$(\alpha p^2 + \alpha + \sigma + Y_o)\theta_z + (\sigma + Y_o)p\theta_x = -C_{21}p\theta_x - (\sigma + Y_o - C_{12})p^2\theta_z + (\sigma + Y_o + C_{21})p\theta_x - C_{12}\theta_z + L_z$$

The conditions placed upon C_{11} and C_{22} are such as to effect the desired cancellation of terms leading to the following decoupled equations:

$$[(1 + \sigma + Y_o)p^2 + (4\sigma + Y_o + 4)]\theta_x = -C_{21}(p^2 + 1)\theta_x + L_x \qquad (3.9)$$

$$[(\alpha + \sigma + Y_o)(p^2 + 1)]\theta_z = C_{12}(p^2 + 1)\theta_z + L_z \qquad (3.10)$$

Note, however, that although the equations are decoupled, Eq. (3.10) has the term $(p^2 + 1)$ common throughout. This means that the characteristic equation for the motion about the z-axis has two pure imaginary roots and that a condition of neutral stability exists about this axis no matter what C_{12} may be chosen to be. Thus, although the x- and z-axis equations have been decoupled, the effort is to no avail, since with this scheme it would be impossible to control the motion about the z-axis properly.

Since there are no effective methods for predicting response of coupled systems, it will be necessary to devise a control scheme by trial-and-error method applied to the analog computer.

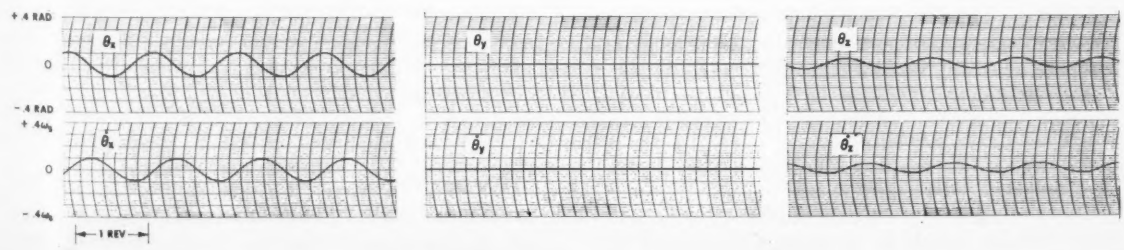


Fig. 15. Forced response: $T_z/I_z = 50 \times 10^{-8}$.

Design of a Particular System

Satellite Configuration

In order to illustrate the response characteristics of a representative control scheme, a satellite with the following inertia ratios has been chosen:

$$\alpha = 0.5 \qquad \beta = 1.5 \qquad \sigma = 0$$

The choices of α, β, and σ may appear to have been completely arbitrary. Conversely, there is an important reason for the choice of the relative magnitudes of α and β, for Roberson has shown that Eqs. (3.1–3), with all terms on the right side of the equations equal to zero, contain no instabilities only when the satellite configuration is such that $I_z < I_x < I_y$. That is to say, a satellite of this configuration, with no controls and with no external torques other than the gravitational differential torques applied, if displaced slightly, will oscillate about the vertical reference but these oscillations will not diverge.

The condition $I_z < I_x < I_y$ is not an overriding consideration in the design, but it is certainly reasonable to remove as many sources of instability as possible within the limits of practical design. Thus the choice of $\alpha < 1$ and $\beta > 1$ meets this "non-instability" criterion. The choices α and β were arbitrarily made to have a difference of unity in order that σ be equal to zero, thus simplifying somewhat the computer simulation of the equations of motion without reducing the generality of the problem.

Control Scheme

It is now necessary to arrive at some practical, workable control scheme primarily by experimental methods in conjunction with the use of the analog computer. Before doing so, it is necessary to decide what functions of the output angles and/or their derivatives the flywheel torques shall be.

Recall that in the linearization of the equations of motion one of the conditions imposed was that at the equilibrium position the angular momenta of the x- and z-axis flywheels be zero. Therefore, not only must the angular momenta X and Z be zero as an initial condition of operation, but also after the correction of any arbitrary displacement, in order that the initial conditions for the succeeding displacements be zero also. This requires that X and Z be proportional to some function which is itself zero in the equilibrium position. All values of the θ_i's and their time derivatives are zero in the equilibrium position. Since the angular momentum of any of the flywheels equals the negative integral of the torque applied by the flywheel on the satellite, the x- and z-axis flywheel torques must be proportional to the first or higher time derivative of an output angle, or some combination thereof, for X and Z to have zero final condition values.

Considering the limitations imposed, the simplest control scheme would be to make $\dot{X}$ proportional to $\dot{\theta}_x$ and $\dot{Z}$ proportional to $\dot{\theta}_z$, along with the possibility that an initial condition of angular momentum on the y-axis flywheel Y_o may improve response. These assumptions permit simplifying the designation of the x- and z-axis controls as follows:

$$X = C_x\theta_x \qquad \dot{X} = C_x\dot{\theta}_x$$
$$Z = C_z\theta_z \qquad \dot{Z} = C_z\dot{\theta}_z$$

where C_x and C_z are proportionality constants. Intuitively, this should provide a satisfactory control system for, as already discussed, a satellite for which $I_z < I_x < I_y$ is inherently neutrally stable for small angular motion even when no control torques are applied. Thus it seems reasonable that, in the absence of any natural damping within the system, the addition of damping torques is basically all that is needed to assure stable response.

Once it has been determined that the response characteristics of the control system configuration described in the foregoing shall be investigated, the only analytical tools available are the Routh Stability Criterion and a derived equivalent open-loop transfer function which would yield the characteristic equation of the coupled system.

Simultaneous solution of Eqs. (3.1) and (3.3) gives the following open-loop transfer function for $\sigma = 0$ and $\alpha = 0.5$:

$$Y_{\theta x,z} = \frac{(Y_o p - C_x)(Y_o p - C_z)}{(p^2 + C_z p + 4 + Y_o)(0.5p^2 + C_z p + 0.5 + Y_o)}$$

Not much insight into system behavior can be gained from this transfer function. Whereas for most control system design one has a transfer function of the form $KG(p)$, where $G(p)$ is defined by the particular system under consideration and the designer has only to choose the gain constant K for desired response, this transfer function contains three variable quantities—C_x, C_z, and Y_o—each appearing both in numerator and in denominator, with no gain constant by which fine system adjustment can be made.

The Routh Criterion merely indicates whether the system is stable or unstable, a fact easily verified on the analog computer.

System Response

In the absence of effective analytical techniques, it has been necessary to investigate system behavior in the x-z plane by computer simulation for various combinations of C_x, C_z, and Y_o. From approximately a thousand different combinations of these three variables, it was found that best response was obtained for the following values of the control parameters:

$$C_x = 0.5 \qquad C_z = 1.0 \qquad Y_o = 0.5$$

For these values, displacement errors are corrected in approximately $1\frac{1}{2}$ satellite revolutions, as shown among the adjacent response plots (Figs. 2 through 8).

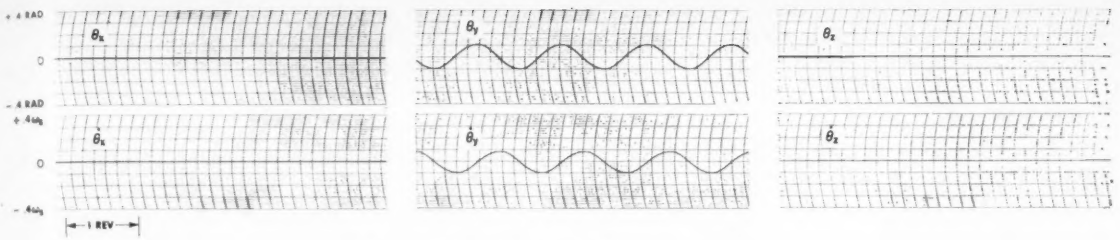


Fig. 16. Forced response: $T_y/I_z = 6.1 \times 10^{-8}$.

Once the system parameters for best response as enumerated above were determined, C_x and C_z were held constant and Y_o was varied to show the effect of imposing the initial condition on the y-axis angular momentum. This is illustrated in the adjacent plots of θ_x, θ_z, $\dot{\theta}_x$, and $\dot{\theta}_z$ vs. time for initial displacements in both θ_x and θ_z. Note that the response time for $Y_o = 0.5$ is approximately half that for $Y_o = 0$.

Y-Axis Controls

As can be seen from Eq. (3.2), satisfactory response can be obtained for the uncoupled y-axis by making $\dot{Y} = C_y\dot{\theta}_y$, where C_y is merely a proportionality constant. The values of principal moments of inertia previously chosen for the satellite define the undamped natural frequency to be one cycle per revolution. For purposes of computer simulation of the nonlinear equations of motion for small angular motion, Eqs. (1.17–19), C_y has been chosen to be 2.0, giving a damping factor of 2/3.

Absolute Nature of Control Torques and Momenta

It should be noted that the nondimensional control torques ($\dot{X}$, $\dot{Y}$, and $\dot{Z}$) and angular momenta (X, Y, and Z) result from the dimensional torque and angular momentum terms contained in Eqs. (1.4–6) and as such are absolute quantities measured with respect to the Newtonian frame. This factor must be taken into account in the actual instrumentation of the control system where it is simpler to measure flywheel angular momentum with respect to the rotating reference system. However, in the normal case, the flywheels will be small and their spin rates high enough that the effects of relative motion will be second order in nature.

Nonlinear Response Characteristics

Analog Computer Simulation

Using the optimum control system parameters obtained by means of the linear analysis, nonlinear system response characteristics were obtained by analog computer simulation of the nonlinear equations of motion for small angular motion, Eqs. (1.17–19). The computer traces are shown through this section.

By the definition of the control system, it is possible to obtain a time history of X, $\dot{X}$, Y, $\dot{Y}$, Z, and $\dot{Z}$ from the plots of the θ's and $\dot{\theta}$'s vs. time as follows:

$$\begin{array}{lll} X = C_x\theta_x & \dot{X} = C_x\dot{\theta}_x & C_x = 0.5 \\ Y = Y_o + C_y\theta_y & \dot{Y} = C_y\dot{\theta}_y & C_y = 2.0 \\ Z = C_z\theta_z & \dot{Z} = C_z\dot{\theta}_z & C_z = 1.0 \end{array}$$

Transient Response

As can be seen from the plots (Figs. 9 through 17), for the same initial conditions the nonlinear response characteristics obtained were almost identical to those obtained by means of linear analysis. Note that there is very little, and in some cases no, interaction between the x-z plane motion and the motion about the y-axis. This is to be expected, in that in the linearization process the y-axis motion became completely decoupled from motion in the x-z plane.

Transient response characteristics were obtained for initial angular displacements of both 0.1 and 0.3 radians about each of the axes individually. Inasmuch as the nonlinear equations for small angular motion were derived from the exact equations of motion by assuming $\sin\theta = \theta$ and $\cos\theta = 1$, it is felt that these equations are good approximations to the

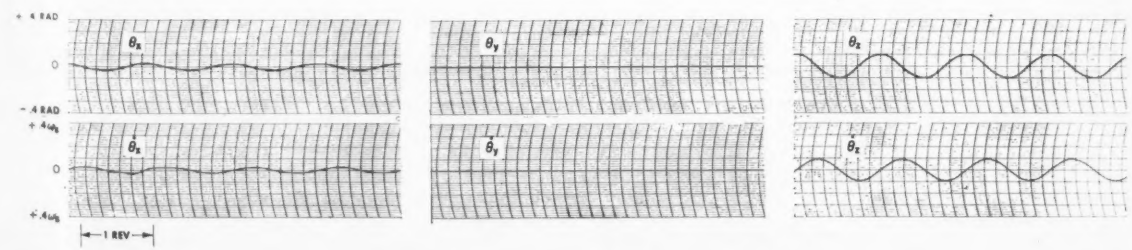


Fig. 17. Forced response: $T_z/I_z = 10.8 \times 10^{-8}$.

Figs. 9–17. Nonlinear response plots (all plots are to same scale).

exact equations only when these assumptions are valid—that is, when the angular deviations are equal to or less than 0.3 radians.

Forced Response

Each of the axes was forced individually by a torque of orbital frequency and of such magnitude as to cause the particular axis being forced to oscillate at maximum amplitude of ± 0.1 radian. Using the relationship that the nondimensional forcing torque L_t equals $Ti/I_x\omega_s^2$ and assuming an orbital period of 90 min to fix ω_s, the torque to inertia ratios necessary to cause the 0.1 radian deviations were

$$T_x/I_x = 50 \times 10^{-8} \text{ for the } x\text{-axis}$$
$$T_y/I_x = 6.1 \times 10^{-8} \text{ for the } y\text{-axis}$$
$$T_z/I_x = 10.8 \times 10^{-8} \text{ for the } z\text{-axis}$$

Conclusions

This research project can best be described as a feasibility study or preliminary design analysis. It is by no means a complete analysis of the problem. To complete the analysis, one would proceed by evaluating the parametric excitation and driving torques mentioned previously and account for same in the equations of motion. It would also be necessary to simulate system response utilizing the exact equations of motion, unrestricted by the assumption of small angular motion, as would be given by utilizing the exact Euler angle transformations. In addition, a comprehensive investigation of the magnitudes of the real external forcing torques described in the section on Design Procedure should be made.

The control system configuration proposed here is only one among many possible configurations. For instance, a nonlinear control system with dead-zones covering the tolerances in angular deviations might be a highly satisfactory and economical control system.

The principal objective of this project has been to illustrate the concept of system design as applied to this particular problem. As such, the selection of control system parameters was based upon the most rapid transient response of the system. Another basis of design would be to select the control parameters such as to minimize steady-state oscillations resulting from periodic forcing torques. It may be that the latter concept would be more satisfactory, depending upon whether impulsive or periodic forcing torques affect the system more critically. A compromise between the two concepts might be most satisfactory.

From the control system definition (as outlined under Analog Computer Simulation), there are two alternatives in implementing the control system—either make the flywheel torque proportional to the angular rate or make its angular momentum proportional to angular displacement, with the Y_o bias on the y-axis flywheel required in either case. The ease in instrumentation would be the major factor in the choice of mechanization of the system.

References

[1] Roberson, R. E., *Attitude Control of a Satellite Vehicle—An Outline of the Problems*, Proc. of 8th International Astronautical Congress, Barcelona, 1957.

[2] Roberson, R. E., *Gravitational Torque on a Satellite Vehicle*, Journal of the Franklin Institute, Vol. 265, No. 1, Jan. 1958.

IAS SCRIP COUPONS

IAS SCRIP COUPONS may now be used as payment for IAS Papers, dues, subscriptions, and all other IAS services. This method will save you from writing checks, sending money orders or cash. Sheets of 5- and 25-cent coupons are available in book form of $5, $10, $25, or any amount desired, from the Special Publications Dept. Scrip may be ordered by foreign and domestic members and nonmembers.

Single Gyro Directional Stability and Control (Continued from page 21)

provide the position and the position-and-rate signals. The PAR ratio, which is the relative magnitude of the position and the rate signals, is determined by the selection of the spring constant. In some applications the position-and-rate signal alone is adequate, such as in target aircraft where no rudder control is required. In other applications, both pickoffs are advantageous and by algebraically combining these signals, a wide variety of control characteristics is feasible.

Flexibility of PAR

The PAR Gyro is inherently a nontumbling, body-axis sensor and may be mounted in any attitude so as to be sensitive to the optimum combination of aircraft motion for the particular application. Fig. 2 illustrates the common usage of the PAR wherein the gyro is canted to sense a trigonometric combination of yaw and roll. For a cant angle of λ, the gyro input rate ω_i is

$$\omega_i = \dot{\psi} \cos \lambda + \dot{\phi} \sin \lambda$$

As shown in Fig. 2, λ is the angle between the airframe roll axis and the gimbal axis, hence λ is the sum of the gyro mounting angle from the aircraft body axis and the aircraft angle of attack α.

For the simplified conditions wherein friction, backlash, integrating nonlinearities, and gimbal inertias are neglected and for a steady state condition, the output of the two gyro pickoffs with suitable external excitation may be expressed as follows:

$$E_p = \omega_i (K_1/S)$$
$$E_{par} = \omega_i[(K_1/S) + K_2]$$

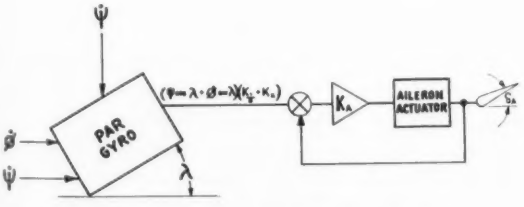


Fig. 4. Lateral control system, target aircraft.

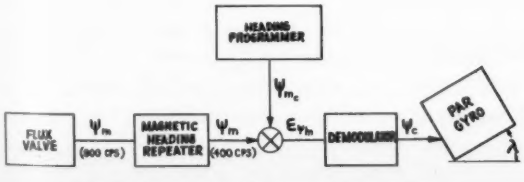


Fig. 5. Heading control, reconnaissance drone.

Then the canting process has developed the following control signals for the simplified assumptions discussed above:

$$E_p = (\dot{\psi} \cos \lambda + \dot{\phi} \sin \lambda)(K_1/S)$$
$$E_{par} = (\dot{\psi} \cos \lambda + \dot{\phi} \sin \lambda)[(K_1/S) + K_2]$$

Command control for systems employing the PAR is accomplished by a d.c. torquer winding that is integral with the existing permanent magnet damper motor, thereby combining functions to attain overall simplicity. The torquer sensitivity is high due to the existing gear train torque amplifier—e.g., a four deg per sec gimbal precession rate

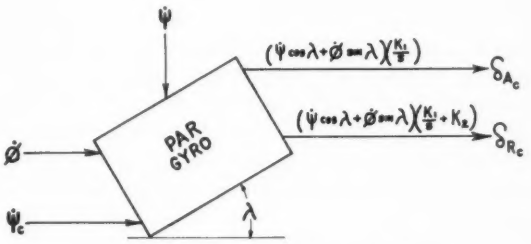


Fig. 6. Two-axis lateral control sensing system.

requires approximately one volt at an impedance level of 600 ohms Fig. 3 shows how a duty cycle modulated ON-OFF command channel is used to attain proportional turn-rate command control. A typical repetition period is one second with a ten-to-one duty-cycle modulation range.

Caging is often a desired gyro capability. The PAR has limited gimbal travel and is a single-degree-of-freedom device, hence single-point, instantaneous mechanical caging is relatively simple to accomplish, where necessary, by a rotary solenoid and cam mechanism. This may be an important consideration in the design of a target or missile control system where a cageable two-degree-of-freedom free gyroscope is often employed and where the complexity, cost and reliability of the caging mechanisms in these types of gyros might be cause for considering the use of the PAR Gyro as an alternate approach. Of interest is the fact that PAR caging is easiest to accomplish at the damper motor end of the spring (Fig. 1) and in this configuration the caged PAR is a conventional, spring-restrained rate gyro and could be used as such.

PAR vs. Directional Gyro

The PAR is a single-degree-of-freedom, null-seeking type of gyro whereas the conventional direc-

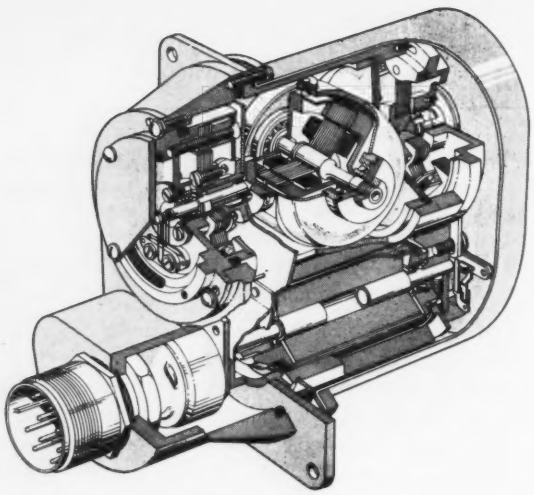


Fig. 7. PAR Gyro (model 268-B).

tional gyro is a two-degree-of-freedom, 360-deg-of-heading type of unit. These two basic differences account for the characteristics of each unit and determine the added circuitry required for each type in the design of a lateral flight control system, wherein a choice of these two types of devices is indicated.

The conventional directional gyro has the inherent gimbal errors during maneuvers that are typical of two-degree-of-freedom gyroscopes and are most serious in the directional gyro application wherein the outer gimbal is apt to be in any position. The equation for calculating gimbal error[1] in heading is

$$\tan \epsilon_\psi = \frac{\tan A_z \, (\cos A_t - 1)}{1 + \tan^2 A_z \cos A_t}$$

For a 45° heading and a 45° inner gimbal tilt angle, the error is 10.1°. This error has a lateral mode destabilizing effect and requires added circuitry, such as a rate gyro and/or lead-lag networks, to overcome this inherent effect. The PAR does not have these destabilizing effects; in fact, it contains a rate as well as a position signal component for stability augmentation.

A second disadvantage of the conventional directional gyro is its basic difficulty to manufacture, hence high cost. By comparison, the PAR is simpler to manufacture and more rugged in nature.

The PAR Gyro is a null-seeking device, hence its best application is in a radio or manually commanded heading-hold flight-control application. The directional gyro has complete 360° freedom and is ideally suited for programed headings—e.g., a reconnaissance drone. However, this disadvantage of the PAR may be overcome by slaving it to a flux valve when programed headings are required. The resulting magnetic system is an absolute heading control system and is not subjected to the gyro drift limitations of the directional gyro system but is subjected to the problems associated with magnetic heading systems. If these magnetic heading problems, most important of which is the poor performance at magnetic latitudes greater than 70 deg, are acceptable, the PAR plus flux valve will provide improved heading control at lower cost than the conventional directional gyro system.

Examples of Uses of PAR

Target Lateral Control System

The PAR is used principally as the sensing instrument for a target lateral control system. In this application, the heading-hold performance is superior to the control system that utilizes bank-attitude control and the Dutch-roll mode stabilization is typically adequate by the use of aileron control only (no rudder). Thus, a gyro with only the position-and-rate output is required, and the simplified lateral control equation is

$$\delta_A = K_3 \, (\psi \cos \lambda + \phi \sin \lambda)[(K_1/S) + K_2]$$

A block diagram of this application is shown as Fig. 4. Typical constants for this system, using existing gyros, are as follows:

$K_1 = 0.75$ volt/deg
$K_2 = 0.19$ volt/deg/sec
$K_3 = 0.4$ deg/volt
$\lambda = 20°$

Reconnaissance Drone Lateral Control System

The use of a flux valve to slave a PAR to a magnetic heading was discussed in the earlier section comparing the relative merits of the PAR vs. the directional gyro. Fig. 5 is a block diagram of the heading control and programer of the flux valve slaved PAR system. The balance of the reconnaissance drone lateral control system would be the same as that shown in Fig. 4 for the target aircraft.

Two-Axis Lateral Control System

Fighter aircraft, missiles and high-performance targets and drones often require heavy Dutch-roll mode damping. For these applications, a rudder loop with a yaw damper subsystem is most effective. The multiplicity of PAR outputs is ideal for this situation. Fig. 6 shows how, as a typical example, the position output signal is used for heading control through the aileron subsystem and how the position-and-rate signal is used to provide a yaw damper in the rudder subsystem. (Note that this technique has been used successfully, as shown, to stabilize and control the TV-2 and A4D-1 aircraft.) For this type of control, the following gain equations are feasible:

$$\delta_A = K_3 \, (\psi \cos \lambda + \phi \sin \lambda) \left(\frac{K_1}{S}\right)$$

Table 1. PAR Gyro Data

Item	Summers Model 268B-4	Summers Model 271D
Weight, lbs.	4.5	4
Size, in.	3 by $4^5/_8$ by $7^5/_{32}$	$3^5/_{16}$ dia by $6^1/_{16}$ length
Gyro motor excitation, volts	400 cps, 3 × 115/200 volts	28 vdc
Gyro motor power, watts	6	7
Gyro motor speed, rpm	23,000	11,600 (governed)
Rotor angular momentum, cgs	0.75×10^6	0.35×10^6
Type pickoff	microsyn	potentiometer
Number pickoffs	2	1
Mechanical caging	yes	no
Heater, watts	34	none
Damper motor resistance, ohms	400	600
Command sensitivity, volts/deg/sec	250	600
Rate sensitivity, deg/deg/sec	0.532	0.5
Position sensitivity, deg/deg	0.266	2.0
PAR ratio (Rate:Pos), sec	2.0	0.25
Natural frequency, cps	7	4
Damping (minimum)	0.2	0.1
Drift (maximum), deg/min	0.5	0.5
Life (minimum), hours	1,000	100
Temperature, °F	−65 to 160	−65 to 160
Vibration, g	5	5
Shock, g for 11 μsec	15	30

$$\delta_R = K_4 (\psi \cos \lambda + \phi \sin \lambda) \left(\frac{K_1}{S} + K_2 \right)$$

Typical values for constants, using existing gyros, are as follows:

$$K_1 = 0.158 \text{ volt/deg}$$
$$K_2 = 0.316 \text{ volt/deg/sec}$$
$$K_3 = 5.0 \text{ deg/volt}$$
$$K_4 = 1.3 \text{ deg/volt}$$
$$\lambda = 10°$$

Available PAR Designs

Two PAR designs have been put into production and qualified to date. Table 1 shows the pertinent characteristic data for these two gyros, and Fig. 7 is a cutaway drawing of the Model 268B PAR Gyro. Since these two units were developed for specific applications, the data shown are not the only available combination of performance capabilities. Certain characteristics are easy to change, others may be changed by minor redesign, and still others would require an overall size change. In these respects the PAR is like other gyros.

As in the conventional rate gyro, the spring is readily changed to create minor changes in PAR ratios, rate sensitivities, natural frequencies, etc. An additional factor is the gear ratio between the gimbal spring and the damper motor. This also can be changed by minor redesign to create a new nominal operating point from which spring changes give a new combination of natural frequencies and so forth. A doubling or halving of the basic spring constant can be accomplished without sacrifice in basic performance. More extensive changes require gear ratio changes.

The two gyro designs described in Table 1 were developed for applications where low cost and weight were of prime importance and heading-hold performance in the 0.5 deg per min area was acceptable and quite superior to existing bank-attitude control systems. The PAR principle of packaging the integrating device with the gimballing system of a rate-sensing gyro to obtain better overall system simplicity and reliability can be extended to the higher drift performance region by the design of larger units to obtain greater rotor inertias.

Reference

[1] Weems, William, R., *An Introduction to the Study of Gyroscopic Instruments*, McGraw-Hill Book Co., Inc., New York, 1948.

✦ ✦ ✦

AN AUTHORIZED BINDING FOR

Aerospace Engineering

Arrangements have been made by the Institute of the Aerospace Sciences for members and subscribers to have their magazines bound carefully and economically. Simply write for details to:
Publishers' Authorized Bindery Service Ltd., 430 West Erie St., Chicago 10, Ill.

Aerodynamic-Influence-Coefficient Procedure

(Continued from page 23)

flow in three dimensions is[2]:

$$\beta^2(\partial^2\varphi/\partial x^2) - (\partial^2\varphi/\partial y^2) - (\partial^2\varphi/\partial z^2) = 0 \quad (1)$$

A solution of which for the thin wing is:

$$\varphi = -\frac{V}{\pi}\int_{S_w}\int \alpha\, R\, d\,\xi\, d\,\eta \quad (2)$$

where the region of integration, S_w, is as shown in Fig. 1.

If the planform is divided into a series of chordwise strips of width $\Delta\eta$ (Fig. 2), and the angle of attack, α, for a given strip considered constant, the contribution of a given strip, J, to the potential at $P(x,y)$ is:

$$\varphi\,(P) = -\frac{\alpha\,(J)\,V}{\pi}\int_{\xi_1}^{\xi_2}\int_{\eta_1}^{\eta_2} R\, d\,\xi\, d\,\eta \quad (3)$$

The spanwise integration limits, η_1 and η_2, are the boundaries of the strip; and the forward and aft limits, ξ_2 and ξ_1, are determined either by the Mach reflection traces or planform boundaries.

It is the pressure coefficient, C_p, rather than the velocity potential that is of interest and

$$C_p = -\,(4/V)\,(\partial\varphi/\partial x) \quad (4)$$

$$C_p(P) = \frac{4\,\alpha(J)}{\pi}\frac{\partial}{\partial x}\int_{\xi_1}^{\xi_2}\int_{\eta_2}^{\eta_1} R\, d\,\xi\, d\,\eta \quad (5)$$

Twisting Planform

Eq. (5) is easily solved for the various influence regions shown in Fig. 1; these solutions are given in Appendixes A and B for the subsonic and supersonic leading edge wing respectively. The specific equation to employ for a given strip-point situation is dependent on the Mach region of P, the strip position, and m. The complete solution procedure for a twisted wing analysis is given in Table 1. Note that the "working-wing" here is the basic planform. If an influence strip does not lie entirely within the intercept limits (Appendix D), the appropriate η value of the pressure equation is modified to consider only that portion of the strip falling within the integration area.

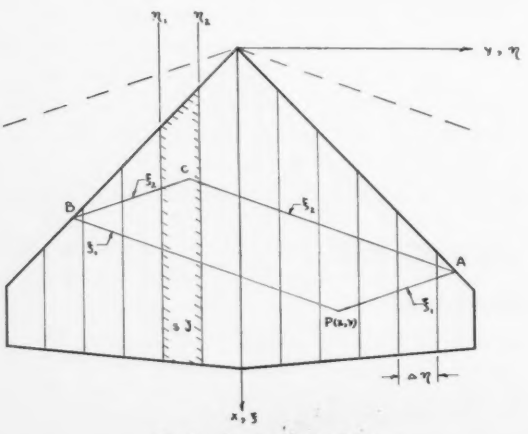
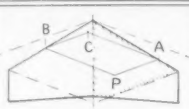
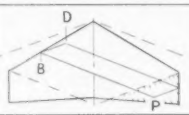
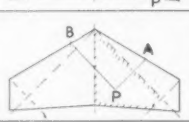
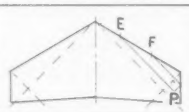
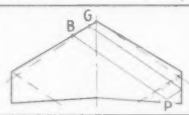
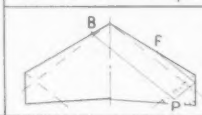


Fig. 2. Planform strip division.

Table 1. Solution Procedure for Twisting Planform

m	Pressure Point Region	P	Strip Limits		Pressure Eq.
≤1		$X+\beta Y<\beta\left(\frac{m+1}{m}\right)$	$\eta_1 \geq \eta_B$ $\eta_1 \geq \eta_C$	$\eta_2 \leq \eta_C$ $\eta_2 \leq \eta_A$	(A-1) (A-2)
		$X+\beta Y>\beta\left(\frac{m+1}{m}\right)$	$\eta_1 \geq \eta_B$	$\eta_2 \leq \eta_D$	(A-1)
>1		$X+\beta Y<\beta\left(\frac{m+1}{m}\right)$	$\eta_1 \geq \eta_B$	$\eta_2 \leq 0$	(B-2) $1<m<\infty$ (B-3) $m=\infty$
		$\beta Y - X < 0$	$\eta_1 \geq 0$	$\eta_2 \leq \eta_A$	(B-1) $1<m<\infty$ (B-3) $m=\infty$
		$X+\beta Y<\beta\left(\frac{m+1}{m}\right)$ $\beta Y - X > 0$	$\eta_1 \geq \eta_E$	$\eta_2 \leq \eta_A$	(B-1) $1<m<\infty$ (B-3) $m=\infty$
		$X+\beta Y>\beta\left(\frac{m+1}{m}\right)$ $\beta Y - X > 0$	$\eta_1 \geq \eta_E$	$\eta_2 \leq \eta_F$	(B-2) $1<m<\infty$ (B-3) $m=\infty$
		$X+\beta Y>\beta\left(\frac{m+1}{m}\right)$ $X+\beta Y>2\beta$	$\eta_1 \geq \eta_B$	$\eta_2 \leq \eta_G$	(B-2) $1<m<\infty$ (B-3) $m=\infty$
		$X+\beta Y>\beta\left(\frac{m+1}{m}\right)$	$\eta_1 \geq \eta_B$	$\eta_2 \leq 0$	(B-2) $1<m<\infty$ (B-3) $m=\infty$
		$X+\beta Y<2\beta$	$\eta_1 \geq 0$	$\eta_2 \leq \eta_F$	(B-1) $1<m<\infty$ (B-3) $m=\infty$

For example, the influence of strip J of Fig. 2 would be:

$$C_p(P) = \text{Eq. (A-1)}(\eta_1,\eta_c) + \text{Eq. (A-2)}(\eta_c,\eta_2) \quad (6)$$

Good agreement was found between the proposed method and the exact solutions of the literature. Typical pressure comparisons for various spanwise twist distributions are shown for subsonic and supersonic leading edge planforms in Figs. 3 and 4 respectively. The trapezoidal wing of the sample problem was analyzed for a 30-equal interval strip-division (15 per semiplanform). A portion of the subsonic leading edge symmetric matrix for the twist sample problem is given in Table 2.

Cambering Planform

For a camber analysis the planform is arbitrarily divided into a series of blocks and slope considered constant over a given block (Fig. 5). The blocks can be coincident with a partial-span control surface if desired. The solution of Eq. (5) for all possible

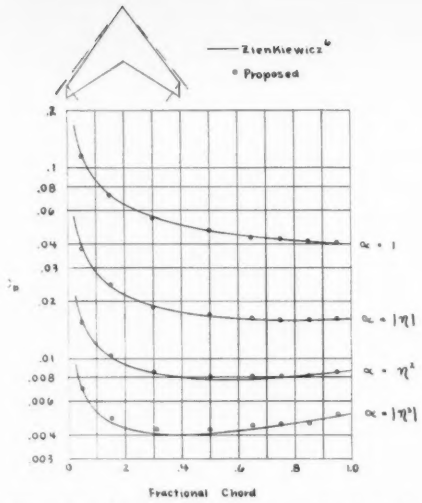


Fig. 3. Comparison of pressure solutions for a subsonic leading edge twisted trapezoidal wing ($Y = 0.5$).

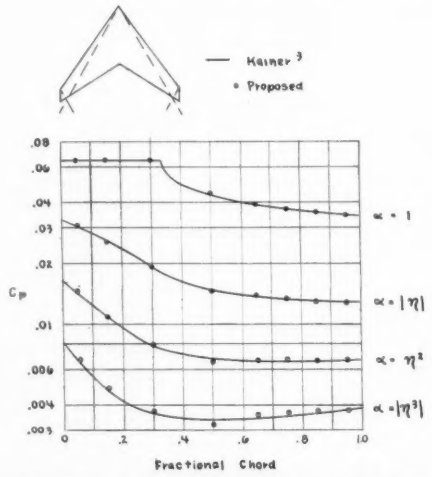


Fig. 4. Comparison of pressure solutions for a supersonic leading edge twisted trapezoidal wing ($Y = 0.5$).

block-Mach pattern arrangements would be difficult. A more promising approach lies in superimposing a series of twisted-wing solutions: the "working-wings" representing flap segments hinged at the spanwise division lines and extending from the "hinge-line" to the trailing edge. The superposition concept of aerodynamic equivalency is illustrated in Fig. 6. Note that α is used only for the leading edge block and a difference slope, δ, is defined for each subsequent block.

In assembling an aerodynamic influence matrix by the superposition concept, the procedure would be as follows. For the wing of Fig. 5 the complete planform, *abf*, would be analyzed first by the procedure of Table 1. For the strip-pressure pattern shown, a 30 pressure point by 12 slope matrix would be obtained. Similarly, analyze successively the working wings *bcf*, *cdf*, *def*, and *ef* (Fig. 6). These results are combined to obtain the net camber matrix, a 30 by 60 array of 1,800 elements. For facility of adaption to an aeroelastic analysis, the column count of the matrix could be reduced by one half by imposing symmetry or antisymmetry on the semiplanform block slopes.

In the analysis of the working-wings, some situations are encountered that require further comment. For the region exterior to the tip Mach cone on the supersonic leading edge wing, the analysis is identical to that of the twisting planform; the equations of Appendix B ($\bar{m} \geq 1, \bar{m} = \infty$) or their alternate form, Appendix C ($\bar{m} < 1$), are used with the working-wing geometry ($\bar{x}$, $\bar{\epsilon}$, $\bar{m}$). For the region interior to the tip Mach cone on the supersonic leading edge wing and the subsonic leading edge wing, two integration situations are possible: the integration may be either from the aft Mach trace to the leading edge of the working wing or to the forward or reflected Mach trace (Fig. 7). For the latter case, the equations of Appendix A are used with the basic planform geometry (x, ϵ, m). Note that for each subdivision analysis the complete pressure point pattern is traversed; the working wing can influence points forward of its leading edge.

To evaluate the proposed method the trapezoidal planform of the twist sample problem was analyzed for a 20-space span division and a 7 equal-space chord division. The net camber matrix was a 70 pressure point by 140 influence block array of 9,800 elements. The agreement with the exact solutions is considered good (Figs. 8 and 9).

Table 2. Portion of the Aerodynamic Influence Matrix for the Sample Problem of Fig. 3

	α_{a1}	α_{a2}	α_{a3}	α_{a4}	α_{a5}	α_{a6}	α_{a7}	α_{a8}	α_{a9}	α_{a10}	α_{a11}	α_{a12}	α_{a13}	α_{a14}	α_{a15}
C_{p1}	.61149	.35943	.52469	.58484	.67644	.82143	1.1586	1.8396	0	0	0	0	0	0	0
C_{p2}	.44714	.27172	.39414	.37765	.38566	.45895	.56756	1.3432	0	0	0	0	0	0	0
C_{p3}	.27766	.37866	.26876	.22939	.25802	.31002	.37437	.57518	.57765	0	0	0	0	0	0
C_{p4}	.26371	.25486	.36442	.16626	.18658	.21186	.25269	.33121	.7.435	0	0	0	0	0	0
C_{p5}	.17317	.26135	.23518	.16199	.15010	.17488	.20316	.25231	.38000	.43476	0	0	0	0	0
C_{p6}	.15623	.17955	.35226	.22446	.14115	.15199	.18047	.21798	.30696	.53585	0	0	0	0	0
C_{p7}	.14964	.16299	.28133	.31162	.12698	.14268	.16175	.19791	.25926	.06198	0	0	0	0	0
C_{p8}	.13582	.14976	.24500	.34238	.11883	.13451	.14682	.17716	.21514	.33939	.31021	0	0	0	0

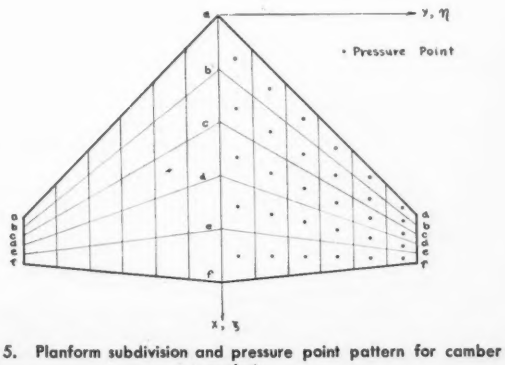


Fig. 5. Planform subdivision and pressure point pattern for camber analysis.

Computation Procedure

The basic solution equations of Appendices A, B, and C are simple and self-explanatory. While it is immediately obvious from a Mach-pattern-planform diagram (Fig. 7) which of the foregoing equations applies to each influence strip-pressure point situation, the digital computer must perform this search and elimination procedure analytically. Since all pertinent relationships may be defined mathematically, these instructions are not difficult to code. The twisting planform procedure is given in its entirety in Table 1; the working-wing analysis entails approximately 20 additional situations, which for brevity are not catalogued herein. As an index of computation time, the sample camber problem (a 70 × 140 influence matrix) was calculated in less than 10 min on the IBM-704 digital computer.

The form of the end product of the basic solution in matrix notation is:

$$\{C_p\} = [A_{PJ}] \begin{Bmatrix} \{\alpha\} \\ \{\delta\}_{RH} \\ \cdots \\ \{\alpha\} \\ \{\delta\}_{LH} \end{Bmatrix} \qquad (7)$$

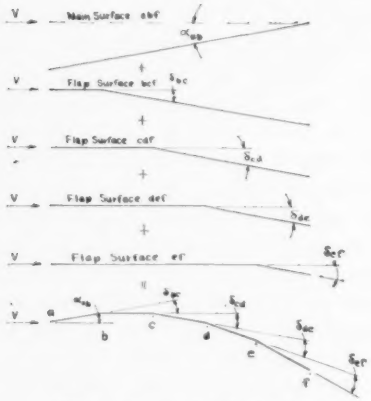


Fig. 6. Superposition for camber.

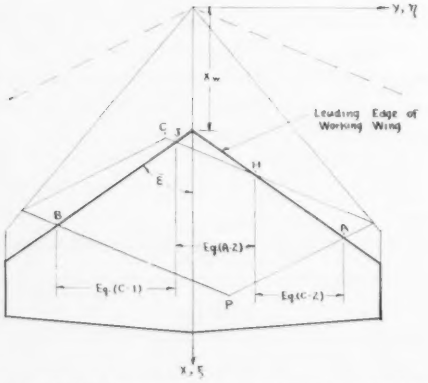


Fig. 7a. Typical solution patterns for working-wing subdivision of a subsonic leading-edge planform (P exterior to tip Mach cone).

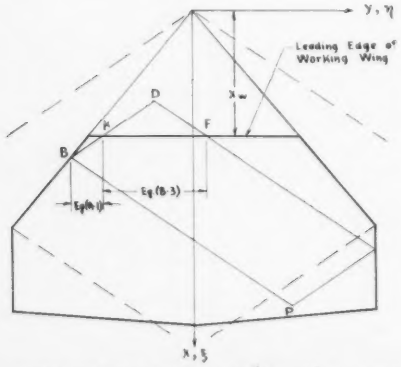


Fig. 7b. Typical solution patterns for working-wing subdivision of a subsonic leading-edge planform (P interior to tip Mach cone).

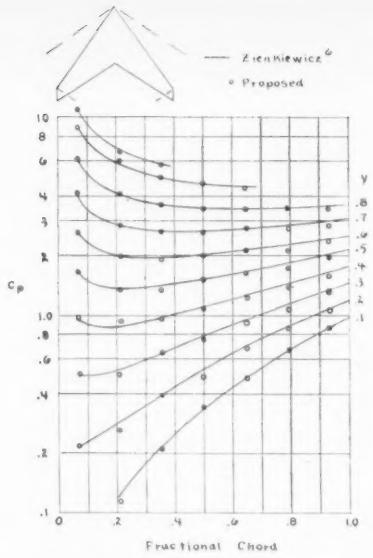


Fig. 8. Comparison of pressure solutions for a subsonic leading-edge cambered and twisted trapezoidal wing (M = 1.2, $\alpha = \eta\xi$).

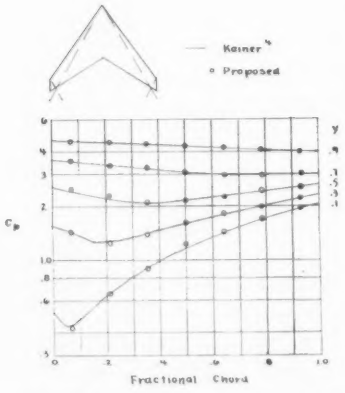


Fig. 9. Comparison of pressure solutions for a supersonic leading-edge cambered trapezoidal wing (M = 2.0, $\alpha = \xi$).

The pressures, C_p, are at a given pattern over the semiplanform, but the block α's, and δ's are for the entire planform. The α's, as explained earlier, are the angle of attack of the leading edge blocks with respect to the free stream; the δ's are the rotation of a block with respect to the one immediately preceding. For the convenience of working with a smaller matrix, in which all the block slopes are presented with respect to the free stream, the following relationships are introduced:

symmetric
$$\begin{Bmatrix}\alpha\\ \delta\end{Bmatrix}_{RH} = \begin{Bmatrix}\alpha\\ \delta\end{Bmatrix}_{LH} \tag{8}$$

antisymmetric
$$\begin{Bmatrix}\alpha\\ \delta\end{Bmatrix}_{RH} = -\begin{Bmatrix}\alpha\\ \delta\end{Bmatrix}_{LH} \tag{9}$$

$$\alpha_i = \alpha + \sum_{i=2}^{i} \delta_j \tag{10}$$

(where the "i"th block is any one in a strip division). Eqs. (8) and (10) or (9) and (10) are incorporated in a matrix operator which when multiplied by the basic $[A_{PJ}]$ matrix will yield a smaller matrix with desired orientation and arrangement.

References

[1] Etkin, B. E., and F. A. Woodward, *Lift Distribution on Supersonic Wings with Subsonic Leading Edges and Arbitrary Angle of Attack Distribution*, Readers' Forum, Journal of the Aeronautical Sciences, Vol. 21, No. 11, pp. 783–785, Nov. 1954.

[2] Evvard, John C., *Distribution of Wave Drag and Lift in the Vicinity of Wing Tips at Supersonic Speeds*, NACA TN 1382, July 1947.

[3] Kainer, Julian H., *Equations for the Loading on Triangular Wings Having Supersonic Leading and Trailing Edges Due to Various Basic Twist Distributions*, Journal of the Aeronautical Sciences, Vol. 20, No. 7, pp. 469–476, July 1953.

[4] Kainer, Julian H., *Equations for the Loading, Section Pitching-Moment Coefficient, and Center-of-Pressure Distributions on Triangular Wings Having Supersonic Leading and Trailing Edges for Various Basic Camber Distributions*, Journal of the Aeronautical Sciences, Vol. 23, No. 2, pp. 137–145, Feb. 1956.

[5] Woodward, F. A., *Aeroelastic Problems of Low Aspect Ratio Wings, Part II Aerodynamic Forces on an Elastic Wing in Supersonic Flow*, Aircraft Engineering, pp. 77–81, March 1956.

[6] Zienkiewicz, H. K., *A Note on Generalized Conical Fields with Applications to Lift of Twisted and Cambered Delta Wings with Subsonic Leading Edges*, English Electric Co., L.A.t. 050, Aug. 26, 1953.

[7] Zienkiewicz, H. K., *Lifting Pressure Distributions on Some Twisted and Cambered Delta Wings with Supersonic Leading and Trailing Edges*, English Electric Co., L.A.t. 052, Sept. 10, 1953.

Appendix A

Equations for Subsonic Leading Edge Twisted Wing

$$C_p(x,y) = \frac{8\,m\alpha}{\beta\pi(m+1)\sqrt{\beta y + mx}} \times \left(\sqrt{m(x-\beta y) + \beta\eta_2(1+m)} - \sqrt{m(x-\beta y) + \beta\eta_1(1+m)}\right) \tag{A-1}$$

$$C_p(x,y) = \frac{8\,m\alpha}{\beta\pi\,(m+1)\,\sqrt{mx-\beta y}} \times \left(\sqrt{m(\beta y + x) - \beta\eta_1\,(1+m)} - \sqrt{m(\beta y + x) - \beta\eta_2\,(1+m)}\right) \tag{A-2}$$

Appendix B

Equations for Supersonic Leading Edge Twisted Wing

$$C_p(x,y) = \frac{4\bar{m}\alpha}{\beta\pi\sqrt{\bar{m}^2-1}} \times \left[\sin^{-1}\left(\frac{(1-\bar{m}^2)\,\frac{\beta\eta_2}{\bar{m}} - \bar{x} + \bar{m}\beta y}{\beta y - \bar{m}\bar{x}}\right) - \sin^{-1}\left(\frac{(1-\bar{m}^2)\,\frac{\beta\eta_1}{\bar{m}} - \bar{x} + \bar{m}\beta y}{\beta y - \bar{m}\bar{x}}\right)\right] \tag{B-1}$$

$$C_p(x,y) = \frac{4\bar{m}\alpha}{\beta\pi\sqrt{\bar{m}^2-1}} \times \left[\sin^{-1}\left(\frac{(\bar{m}^2-1)\,\frac{\beta\eta_2}{\bar{m}} - \bar{x} - \bar{m}\beta y}{\beta y + \bar{m}\bar{x}}\right) - \sin^{-1}\left(\frac{(\bar{m}^2-1)\,\frac{\beta\eta_1}{\bar{m}} - \bar{x} - \bar{m}\beta y}{\beta y + \bar{m}\bar{x}}\right)\right] \tag{B-2}$$

$$C_p(x,y) = \frac{4\alpha}{\beta\pi}\left[\sin^{-1}\left(\frac{\beta(\eta_2 - y)}{\bar{x}}\right) - \sin^{-1}\left(\frac{\beta(\eta_1 - y)}{\bar{x}}\right)\right] \tag{B-3}$$

Appendix C

Equations for Cambered Working Wings

$$C_p(x,y) = \frac{4\bar{m}\delta}{\beta\pi\sqrt{1-\bar{m}^2}} \times \log\left|\frac{2c_1\eta_1 - c_2 + 2\sqrt{c_1^2\eta_1^2 - c_1c_2\eta_1 - c_1c_3}}{2c_1\eta_2 - c_2 + 2\sqrt{c_1^2\eta_2^2 - c_1c_2\eta_2 - c_1c_3}}\right| \tag{C-1}$$

$$c_1 = \frac{\beta^2}{\bar{m}^2}(\bar{m}^2-1) \qquad c_2 = \frac{2\beta}{\bar{m}}(\bar{m}\beta y + x) \qquad c_3 = \bar{x}^2 - \beta^2 y^2$$

$$C_p(x,y) = \frac{4\bar{m}\delta}{\beta\pi\sqrt{1-\bar{m}^2}} \times \log\left|\frac{2c_4\eta_2 + c_5 + 2\sqrt{c_4^2\eta_2^2 + c_4c_5\eta_2 + c_4c_6}}{2c_4\eta_1 + c_5 + 2\sqrt{c_4^2\eta_1^2 + c_4c_5\eta_1 + c_4c_6}}\right| \tag{C-2}$$

$$c_4 = \frac{\beta^2}{\bar{m}^2}(1-\bar{m}^2) \qquad c_5 = \frac{2\beta}{\bar{m}}(\bar{m}\beta y - \bar{x}) \qquad c_6 = \bar{x}^2 - \beta^2 y^2$$

Appendix D

Intercept Equations

$$\eta_A = \frac{\bar{m}\,(\bar{x} + \beta_y)}{\beta\,(\bar{m} + 1)} \qquad \text{(D-1)}$$

$$\eta_B = \frac{\bar{m}\,(\beta y - \bar{x})}{\beta\,(1 + \bar{m})} \qquad \text{(D-2)}$$

$$\eta_C = \frac{y(m - 1)}{m + 1} \qquad \text{(D-3)}$$

$$\eta_D = \frac{\beta\,(1 + m) - mx - \beta y}{\beta\,(1 + m)} \qquad \text{(D-4)}$$

$$\eta_E = \frac{\bar{m}\,(\bar{x} - \beta y)}{\beta\,(1 - \bar{m})} \qquad \text{(D-5)}$$

$$\eta_F = \frac{\bar{m}\,(\bar{x} + \beta y - 2\beta)}{\beta\,(1 - \bar{m})} \qquad \text{(D-6)}$$

$$\eta_G = \frac{\bar{m}\,(-\bar{x} - \beta y + 2\beta)}{\beta\,(1 + \bar{m})} \qquad \text{(D-7)}$$

$$\eta_H = \frac{x_w - \left(\frac{1 - m}{1 + m}\right)(\beta y + x)}{\beta\left(1 - \frac{1}{\bar{m}}\right)} \qquad \text{(D-8)}$$

$$\eta_J = \frac{x_w - \left(\frac{1 - m}{1 + m}\right)(\beta y + x)}{\beta\left(1 + \frac{1}{\bar{m}}\right)} \qquad \text{(D-9)}$$

$$\eta_K = \frac{-x_w + \left(\frac{1 - m}{1 + m}\right)(x - \beta y)}{\beta\left(1 - \frac{1}{\bar{m}}\right)} \qquad \text{(D-10)}$$

✦ ✦ ✦

Approximations in Flight Optimization Problems (Continued from page 27)

Using Eq. (2), Eq. (11) may be integrated, as in Refs. 5 and 6, to yield t and h as functions of v, and m and T may be subsequently obtained from Eq. (1) as functions of v.

This solution is preceded in time by a period of maximum thrust. In the *ideal* case where there is no upper limit of thrust ($T_{max} = \infty$), the ascent begins with an impulse: $h(0^+) = 0$, $m(0^+) < m_0$, $v(0^+) = c \ln [m_0/m(0^+)]$. The computation for this ideal case proceeds backward as in Refs. 5 and 6: (a) Choose a value for H; (b) solve Eqs. (3) and (10) for h_1 and v_1 making use of the series:

$$\int_{z_1}^{z_2} e^{-z}\frac{dz}{z} = \ln\frac{z_2}{z_1} - \frac{z_2 - z_1}{1 \cdot 1!} + \frac{z_2^2 - z_1^2}{2 \cdot 2!} - \cdots$$

(c) use the integrated form of Eq. (11) to find $v(0^+)$ corresponding to $h = 0$; (d) use Eq. (1) to find by integration the value $m(0^+)$; (e) compute m_0. Repetition of this procedure for various H yields a plot of H vs m_0.

2. Unorthodox Solution

Here we set $\lambda_h \equiv 0$ and omit the first Eq. (5) and first Eq. (6). In this case

$$\frac{d}{dt}\left(\frac{\lambda_v}{m} - \frac{\lambda_m}{c}\right) = \frac{\lambda_v}{m^2}\left[\frac{\partial D(h,v)}{\partial v} + \frac{D(h,v)}{v}\right]$$

which must be positive. It follows that $\lambda_v/m - \lambda_m/c$ increases steadily. This implies that maximum available thrust must be used *throughout* the boost. In the ideal case where $T_{max} = \infty$ this means that all the fuel is consumed during the initial impulse. The altitude H reached is then computable directly from Eq. (3), with $h_1 = 0$ and $v_1 = c \ln (m_0/m_1)$.

Numerical Comparison

Let us consider the numerical example presented in Ref. 6:

$$W/m_1 = 10^{-5}\ \text{ft}$$
$$c = 5{,}500\ \text{ft/sec}$$
$$\frac{1}{\alpha} = 22{,}000\ \text{ft}$$
$$g = 32.2\ \text{ft/sec}^2$$

with $(m_0/m_1) = 3.14$.

The orthodox solution yields $H_A = 488{,}950$ ft. The unorthodox solution yields $H_B = 404{,}800$ ft. Thus, the unorthodox solution yields about 17 percent less altitude than the orthodox solution.

References

[1] Lu Ting, *Approximating Technique for Variational Problems*, AEROSPACE ENGINEERING, Vol. 20, No. 1, p. 32, Jan. 1961.

[2] Dommasch, D. O. and Barron, R. L., *Optimum Rocket Trajectories: Part I, Initial Value Variational Solutions*, AEROSPACE ENGINEERING, Vol. 19, No. 1, Jan. 1960.

[3] Dommasch, D. O. and Barron, R. L., *Optimum Rocket Trajectories: Part II, Generalized Boost Analysis*, AEROSPACE ENGINEERING, Vol. 19, No. 2, Feb. 1960.

[4] Breakwell, John V., *The Optimization of Trajectories*, J. Soc. Indust. Appl. Math., Vol. 7, No. 2, June 1959.

[5] Tsien, H. S. and Evans, R. C., *Optimum Thrust Programming for a Sounding Rocket*, J. Am. Rocket Soc., Vol. 21, No. 5, 1951.

[6] Leitmann, G., *Optimum Thrust Programming for High-Altitude Rockets*, AERONAUTICAL ENGINEERING REVIEW, June 1957.

Tri-Service VTOL competition, the prospect of these aircraft in actual use draws nearer. Although the problems to date have been primarily technical and dependent upon advances in the state of technology for their solution, the future problems may well be predominantly those associated with actual operations.

The problems of stability, control and transition, while formidable, appear to be as far along in their solution as were similar problems with conventional airplanes and with helicopters just a few years back. Our tools for analysis and investigation coupled with extensive experimental experience on the part of engineers, scientists, and pilots should permit direct and rapid attack on the questionable or undesirable characteristics introduced with the new hybrid configurations. This suggests that, although probably design and construction will have to anticipate many knotty problems associated with all aspects of flight operations, the first aspect is that associated with control and related stability. The second is the use of transition for maneuvering or conversely applying feasible restrictions on maneuver in the transition regime. Third is the question of selecting "design points" in vehicles which inherently provide a degree of flexibility in loading and operation with which we have little or no experience.

In the simplest terms, control mechanisms have been developed for helicopters which have reached a degree of standardization and acceptance, and control mechanisms have been developed for fixed wing machines which have also been relatively standardized. It will be difficult to determine the proper design and control philosophy to provide "natural" control movements properly associated with vehicle response in craft having flight modes in both regimes. There are all sorts of changes in axis and directions of motion of the vehicle which are not compatible if either of the two distinct philosophies are applied over the whole range from hovering to high-speed translational flight. This problem will not be settled by any arbitrary selection of a system convenient for a particular configuration. Certainly for military use, the question of training and transition from and to V/STOL types will be a serious matter. Some solutions evolved for machines with the broader flight spectrum might be advantageously adaptable to existing helicopters and fixed wing machines, but if these involve significant alterations in concepts, mechanisms and procedures of the traditional configurations, they will probably be automatically rejected.

Transition from hover to translational flight is a relatively simple matter for helicopters. But even here, there are profound changes in attitude and some changes in basic philosophy of control which can only be mastered by experience. There are, of course, all sorts of mixed responses in fixed wing control too. Where the configuration of the machine may be altered in the process of transition between the two regimes, there are apt to be delicate regions where maneuvering margins for safety or intentional deviation in path are extremely slim. It may be satisfactory from an academic design viewpoint to ensure that there is a precise procedure which will *permit* transition with stipulated margins of safety. For instance, if the stipulated procedure is followed, there are no catastrophic stall characteristics encountered. For some missions or uses, the vertical flight capability will be solely for making contact with the ground. A transition path a few feet off the ground can be used in lieu of a ground run for either take-off or landing. There may be economic justification for such concepts, but the inherent utility of the machine is prejudiced unless a considerable use can be made of the hover capability and unless ground rolls can be used advantageously when available. For some military missions, it would be desirable to use acceleration from zero speed to maximum and deceleration from high forward speed down to zero as an added element in the maneuver spectrum. Further, it would be desirable to negotiate changes in configuration to increase performance while in these maneuvers. Not only is the design process greatly complicated by providing such a wide range of operation, but the selection of the range itself must be carefully matched with the operational requirements of the vehicle in service. This is related directly to the problem of control and control mechanisms as well as to the layout of the machine, its power and all related systems.

The overall power and lift values that appear to describe V/STOL machines regardless of the configuration indicate certain inherent capabilities in lifting capacity and power required when related to forward motion. For instance, in the hovering configuration it may be expected that the payload which can be lifted will be somewhat less than that of a helicopter of the same power. If a figure of 30 percent of the gross weight were taken as the payload for a helicopter, the corresponding payload for a V/STOL in the hovering regime might be 25 percent of gross weight. This weight ratio and the associated power is not unreasonable for the kind of high-speed performance that may be expected for the aircraft when configured to use its power efficiently for cruise. With some small forward speed, the same effect as experienced in helicopters may be anticipated. Here inflow is provided by translation and an increased load can be lifted or carried with

the same power. A reasonable approximation is that the payload can be doubled resulting in something like 40 percent of gross. This low-speed translation results in the short take-off, and presumably the corresponding short landing. If higher translational speeds are used, the payload may be increased further to about three times the original resulting in something like 50 percent of gross weight. These estimates do not have to be precise to illustrate the nature of the problem. Which payload is properly used for structural design? Which volume is most appropriate for the expected missions and the general arrangement? On what weight basis is the craft certificated?

After the compromises and decisions have been reached and the machine is in service, there are more problems which do not seem to have any reasonable solutions at the moment. An operator would naturally like to carry as much payload as possible to make the economics attractive. He will therefore elect to carry additional load as take-off and landing run are available. If he assumes that the run available will permit doubling the payload, what regulations apply for safety in cases of partial power failure? A landing made with low fuel may permit a vertical landing, but the take-off may be made with a payload which is appropriate to an available ground run. Therefore, every single flight involves an *ad hoc* decision which takes into account field available at each end, wind, landing conditions, payload, fuel and time of flight. While these elements are present in every flight today with familiar aircraft, there will be a normal use of all the margins in each factor in the V/STOL. Since the same variations exist with regard to power required, a four engined machine with two engines inoperative could quite safely operate as a conventional plane starting out with two engines. But now what field length is approved, and how real is the possibility of permitting regular flight operations with inoperative power plants? An inadvertent miscalculation may lead to attempting a vertical landing with a load requiring a running touchdown. It is conceivable that some machine arrangements may require selecting a configuration for an intended approach and be considerably inferior for all other modes of operation when in this configuration. Such a situation could magnify the error to catastrophic proportions. In the event of accident, there will be an extremely difficult task to apportion responsibility when the selection of load is influenced by so many factors and when the pilot in each case acts almost as his own regulating authority.

The technology has at long last provided a basis for introducing a whole new measure of utility and flexibility in aircraft, but the problems of safe and efficient utilization of the vehicles are much more complex than anything previously experienced. It will require a much more profound appreciation of the operating considerations on the part of the engineers and designers if the new era is to be ushered in with anything like a satisfactory exploitation of the inherent increases in performance which appear to be available. These considerations will certainly be the worry of the engineers for a long time before they become the operator's problem and it will be extremely rewarding to all concerned if they are explored early and provided for in the first operational V/STOL craft.

✦ ✦ ✦

Adventures in Engineering

(Continued from page 31)

absorbed the cost of the initial set of tools and dies. It was determined, however, that once the dies were made, the cups could be fabricated for $1.50 apiece in short run quantities of approximately 100. Of course, the cost of a special set of tools and dies depends on the type of cup desired. However, the estimated cost of a set of dies for normal size recording cups (6-in. dia or less), with a depth of up to 1 in., is in the vicinity of $200.

(Requests for further information addressed to the Editor will be forwarded.)

✦ ✦ ✦

INTERNATIONAL AEROSPACE ABSTRACTS

A monthly service providing fast, comprehensive coverage of the world's aerospace literature.

Access to publications abstracted is provided by the IAS Library in New York City.

Subscription Rates—

Domestic and Foreign.....$60 per year
IAS Corporate Member....$40 per year
IAS Member.....$20 per year

INSTITUTE of the AEROSPACE SCIENCES

2 East 64th Street New York 21, N. Y.

Personnel Opportunities

This section is for the use of individual members of the Institute seeking new connections and eligible organizations offering employment to specialists in the aerospace industry. Any member or eligible organization may have requirements listed without charge by writing to the Secretary of the Institute.

Wanted

Aeronautical Engineers—Civil Aeronautics Board has need for aeronautical engineers, males only, with good backgrounds in structures, systems, and/or power plants—GS-11, $7,560; GS-12, $8,955; GS-13, $10,635 per annum—headquarters in Washington, D.C. Duties in the investigation of aircraft accidents and analyses of reports of other specialists to determine the probable cause and manufacturing or operating changes required to prevent recurrence of similar accidents. Considerable travel involved. Requirements are a degree in aeronautical, mechanical, or electrical engineering or the equivalent in education and/or experience, plus 3 years of progressively responsible aeronautical engineering experience. Apply Personnel Section, Civil Aeronautics Board, Room 506, Universal Building, 1825 Connecticut Ave., N.W., Washington 25, D.C.

Engineers and Scientists—Electronics Research Directorate of the Air Force Cambridge Research Laboratories announces professional staff vacancies for **Engineer** (Electronics); **Physicist** (Electronics, Electromagnetics, Plasmas, Solid State); **Mathematician**; **Chemist** (Physical Analytical, Nuclear). These vacancies are within the Federal Civil Service and offer liberal leave benefits, payment of expenses incurred by employees and their families in moving to Bedford, an extensive program of sponsored education, and an opportunity to pursue a stable program of non-time-oriented research. Graduate level scientific personnel interested in positions described are invited to write or call Francis McWilliams or John Cooney, at CRestview 4-6100, Ext. 3633 or 3758 at Hanscom Field, Mass.

126. Missile Heat Transfer—M.S. or Ph.D in mechanical, aeronautical, or chemical engineering with emphasis on re-entry body heat-transfer analyses. The individual should have a working knowledge of advanced concepts and methods of analyses for defining optimum performance of re-entry bodies from a thermal viewpoint. Effort is of a research nature with emphasis on analytical rather than experimental approach. All applicants will receive consideration regardless of race, creed, color, or national origin.

Notices of all change of address should be sent to the Circulation Department, Institute of the Aerospace Sciences, Inc., 2 East 64th Street, New York 21, N.Y., at least 30 days prior to change of address.

The number preceding the notice represents the Box Number of the Institute of the Aerospace Sciences to which inquiries should be addressed.

Available

132. Director—Research, Engineering, or Planning—Age 39, M.S. in A.E., Registered P.E., AFIAS. Eighteen years' extensive experience in scientific and management fields as consultant, director of research, and general manager with well-known company in aerospace and related fields. Has proved capabilities in planning, organizing, and administering successful programs—completed on schedule and at a profit. Familiar with USAF, USN, Army, and many commercial companies' plans. Desires responsible position with dynamic growth company.

131. Engineer—M.E., M.S. Fifteen years' experience in research and development on electromechanical devices and systems. Includes 9 years in design and evaluation of inertial guidance components and systems. Now Manager of Analysis for large manufacturer.

130. Engineer - Designer - Draftsman—Age 50. Thirty years' experience in drafting, design, and engineering of airframes, turbine engines, automotive parts, fans, blowers, superchargers, airmotors, valves, and fittings. Two years in aircraft engine stress analysis. Registered Professional Engineer (M.E., Indiana). Salary open. Résumé on request.

129. Aero/Mechanical Project Engineer—Seeking position with a growing stable company. Over 10 years' diversified background as a project, development, and application engineer in aircraft structural and mechanical design; electromechanical, hydraulic, and pneumatic controls; rotating machinery including small turbines. Familiar with control dynamics, filament wound fiberglass structures, and cryogenics. B.S. Aero Engineering, Post Graduate Industrial Management. Former USAF and civilian pilot. Prefer a medium-sized equipment company in Northeastern coastal location. All replies considered. Résumé on request.

128. Stress Engineer—Age 30. Two years' experience in preliminary design on hydraulics and pneumatics, plates and pressure vessels from high heat-treat materials. Desires career position in New York, Connecticut, New Jersey vicinity. Location near university preferred. Résumé upon request.

127. Head and Professor—Aeronautical (or Mechanical) Engineering Department. Strong background in aircraft structures, theoretical and applied mechanics, rotary wing aerodynamics, and heat transfer. Eighteen years' teaching and industrial experience. Interested in developing graduate and undergraduate curricula to meet modern engineering problems. Analysis and research oriented. Currently Associate Professor. B. Aero E., and M.S. in Aero E., and Eng. Mech. P.E. Age 41.

125. Heat-Transfer Specialist—Age 32. M.S. (M.E.). Course work (30 units) for Ph.D. Five years' experience in stagnation region heat transfer and temperature control of electromechanical systems. Four years' teaching thermo, heat power, machine design. Experience in transient analysis, boundary layer, analog and digital computer applications, proposal writing, hardware design and testing. Publications. Present salary $14,000/year.

The IAS Library

Publications treated in *International Aerospace Abstracts* are maintained by the Library for use by the IAS Membership. They are *not* for sale but are made available through the facilities of the Library.

LENDING SERVICES: Institute members, both Individual and Corporate, may borrow periodicals, reports, and books for a period of 2 weeks, excluding time in transit. Excepted are certain reference books and those IAS publications that may be purchased.

PHOTOCOPY SERVICES: The Library is equipped to provide, as a service, positive photocopies of certain materials in its collections. Rates on request.

For detailed information about these and other services, write to:

John J. Glennon, Manager
Technical Information Service
Institute of the Aerospace Sciences, Inc.
2 East 64th Street
New York 21, New York

A word about our Advertisers

The many companies whose advertising appears in this issue are interested in you and your work. They are anxious to let you know what they are doing to help you solve research and design problems in missile, rocket, air, and spacecraft projects.

AEROSPACE ENGINEERING's advertising pages keep you posted on new and improved materials, components, services, and supplies useful to your professional work.

To request more information on any product or service advertised, may we suggest you write to the *advertiser* directly, at no obligation to you. It would be greatly appreciated if you would mention that you saw the ad in AEROSPACE ENGINEERING.

AEROSPACE ENGINEERING
Established 1934
2 E. 64th St., New York 21, N. Y.

Index to Advertisers

Aerospace Engineering 49

Aerospaco & Defense Products, The B. F. Goodrich Co. 32, 33
The Griswold-Eshleman Co.

AiResearch Mfg. Divs., The Garrett Corp. ..... inside front cover
J. Walter Thompson Co.

American Machine & Foundry Co., Government Products Group ..... inside back cover
Cunningham & Walsh, Inc.

Bell Telephone Laboratories 2
N. W. Ayer & Son, Inc.

Douglas Aircraft Co., Inc. ..... outside back cover
J. Walter Thompson Co.

Electronic Communications, Inc. 37
Alfred L. Lino & Associates

Garrett Corp., The, AiResearch Mfg. Divs. ..... inside front cover
J. Walter Thompson Co.

B. F. Goodrich Co., The, Aerospace & Defense Products 32, 33
The Griswold-Eshleman Co.

Government Products Group, American Machine & Foundry Co. ..... inside back cover
Cunningham & Walsh, Inc.

IAS News 41

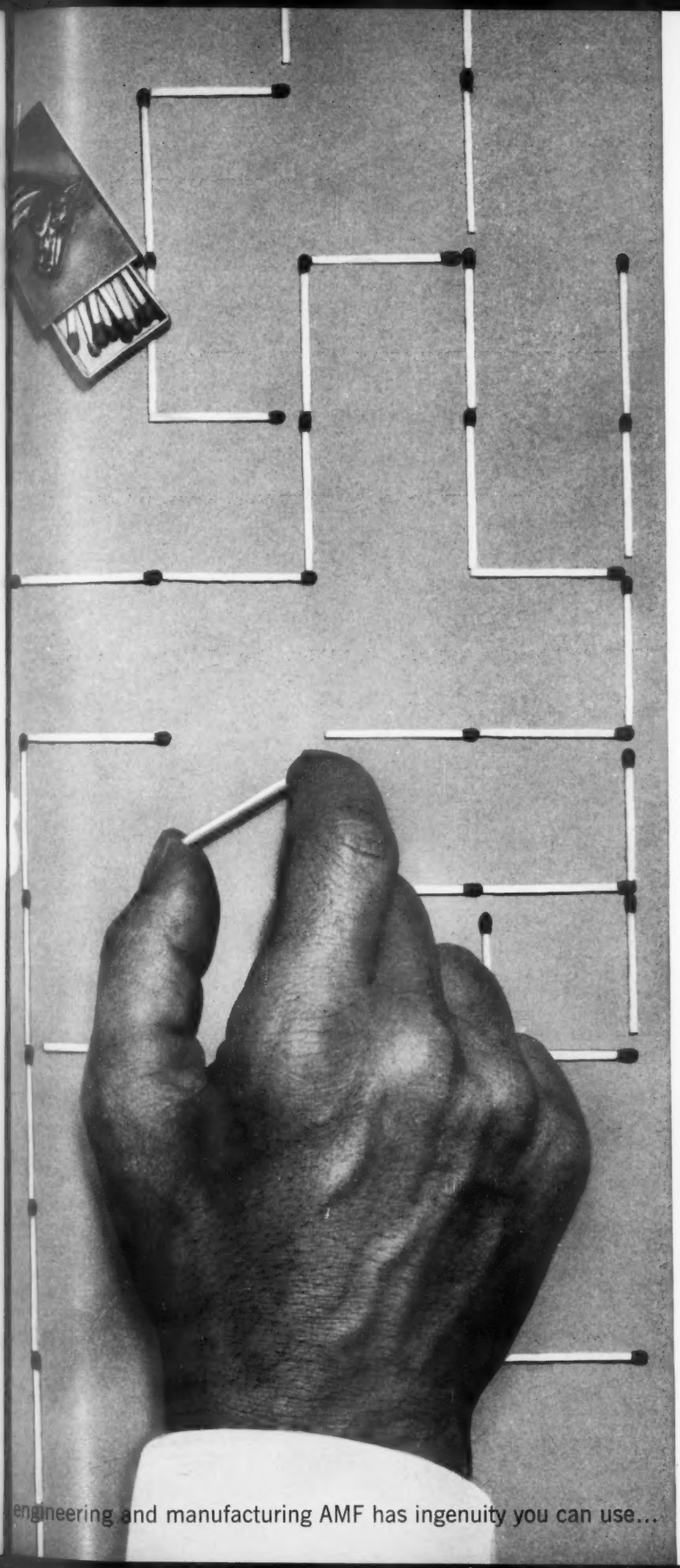
Los Angeles Division of North American Aviation, Inc. 6, 35
Batten, Barton, Durstine & Osborn, Inc.

National Research Council 45

J. S. Staedtler, Inc. 39
Geer, DuBois & Company, Inc.

United Technology Corp. 1
Campbell-Ewald Co.

Vinco Corp. 5
Rolfe C. Spinning, Inc.



He designed a new interchange for radio traffic

This AMF engineer, part of an AMF-U.S. Army team, solved the problem of traffic delays and personal danger in manual re-connection of jumpers when interchanging R.F. transmitters and antennas.

His solution is a push-button-operated, coaxial crossbar switching system, using vacuum switches for circuit selection. A typical system consists of 4 transmitter inputs, 7 antenna outputs plus a dummy load, in a 4 x 8 matrix that can be mounted in a 19″ rack. It can be controlled locally or remotely over any type of communication network having a bandwidth of at least 200 cycles.

AMF's coaxial crossbar switching system provides 100% flexibility in circuit path selection and accommodates power levels as high as 500,000 watts and frequencies up to 30 megacycles. It allows 100% utilization of all transmitting equipment. Stubs are automatically eliminated.

To insure fail-safe operation, power is required for the vacuum switches *only* during change of condition. Selection rate: 1 per second. Operating transmitters are safety-interlocked to insure a load. There are no hazards from open wires or inadvertent application of power to dead-lined antennas.

Single Command Concept

AMF's imagination and skills are organized in a *single operational unit* offering a wide range of engineering and production capabilities. Its purpose: to accept assignments at any stage from concept through development, production, and service training...and to complete them faster...in

- *Ground Support Equipment*
- *Weapon Systems*
- *Undersea Warfare*
- *Radar*
- *Automatic Handling & Processing*
- *Range Instrumentation*
- *Space Environment Equipment*
- *Nuclear Research & Development*

GOVERNMENT PRODUCTS GROUP,
AMF Building, 261 Madison Avenue,
New York 16, N. Y.

AMF

AMERICAN MACHINE & FOUNDRY COMPANY

engineering and manufacturing AMF has ingenuity you can use...

A look at what's ahead in the realities of space exploration

Some predictions from Douglas —builders of Thor which has launched 80% of all successful U.S. satellites & space probes in the past two years

Our mastery of space has advanced so rapidly that only diehard pessimists doubt the moon and planets will know our footsteps within a few decades.

Already a vehicle capable of orbiting a 19,000-pound payload, or driving 5,000 pounds to escape velocity, or lofting 2,500 pounds to Mars or Venus is being built in the U.S. This is Saturn, taller than a 14-story building, with an initial thrust of 1.5 million pounds. Its second stage, under construction for NASA by Douglas, will use a cluster of liquid hydrogen-oxygen engines of unique design.

The world knows a man can rocket into space and return. Can he survive for long periods? Douglas studies give a strong affirmative. Zero gravity and artificial G require further study. Radiation is a continuing problem, but reports from Discoverer XVII, one of 46 space projects launched by the Douglas Thor rocket, show the threat less serious than was first thought.

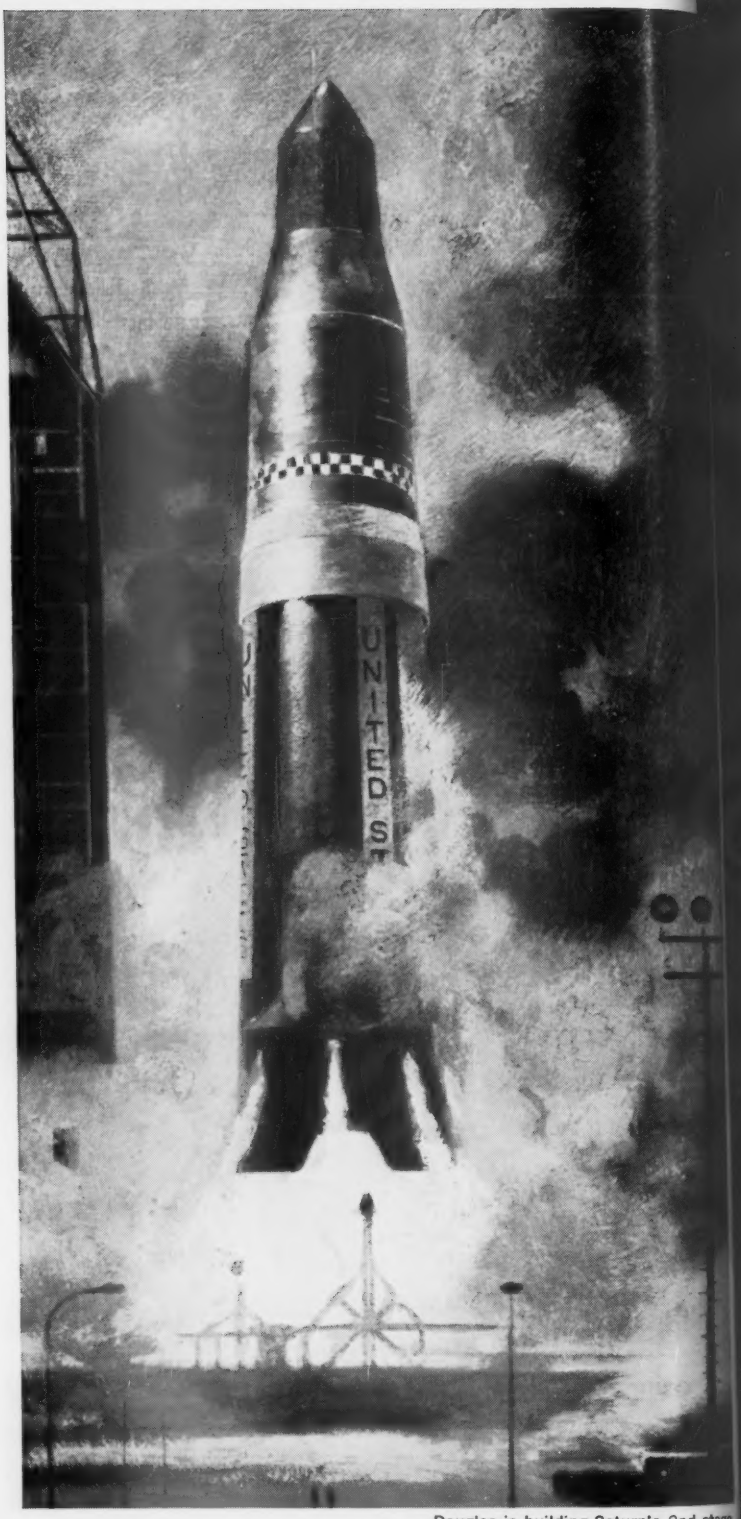
The cost of space travel? A breakthrough in nuclear power, which Douglas engineers confidently predict, should cut the operational cost of a trip to the moon to about $900 per passenger. Other power sources, already under study, may even open such stars as Sirius and Alpha Centauri to travel.

The DC-8 Jetliner, an example of Douglas aero-space leadership

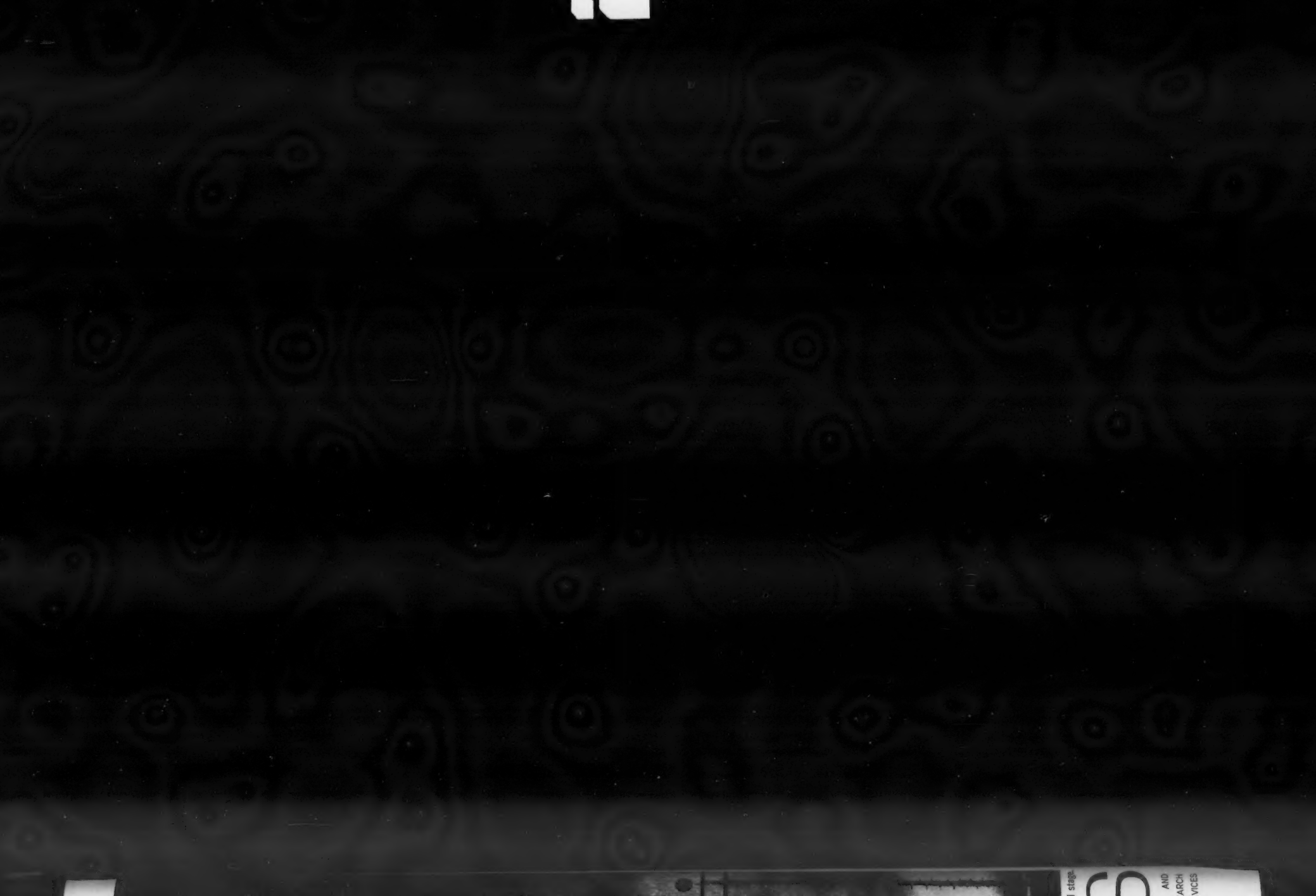
Few of us will ever be lunar commuters, but growing millions are learning about a new kind of travel through the DC-8 jet.

Here is an airplane that slices through time at 10 miles a minute, opens the world to all who have an urge to get up and go places.

Next trip, fly a DC-8 jet, newest of which is the DC-8 Series 50, fastest long-range jetliner in the sky.



Douglas is building Saturn's 2nd stage.

DOUGLAS

DOUGLAS AIRCRAFT CO., SANTA MONICA, CALIFORNIA • MAKERS OF MISSILE AND SPACE SYSTEMS • MILITARY AIRCRAFT • DC-8 JETLINERS • AIRCOMB® • RESEARCH AND DEVELOPMENT PROJECTS • GROUND SUPPORT EQUIPMENT • ASW DEVICES